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(54) **IGNITION CONTROL SYSTEM FOR INTERNAL COMBUSTION ENGINE**

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F02P 17/12 (2006.01)
H01F 38/12 (2006.01)

(52) **U.S. Cl.**

CPC ***F02P 3/04*** (2013.01); ***F02P 17/12*** (2013.01); ***H01F 38/12*** (2013.01)

(58) **Field of Classification Search**

CPC F02P 3/04; F02P 11/00; F02P 11/02; F02P 11/06; F02P 17/00; F02P 17/12; F02P 2017/121; H01F 38/12

See application file for complete search history.

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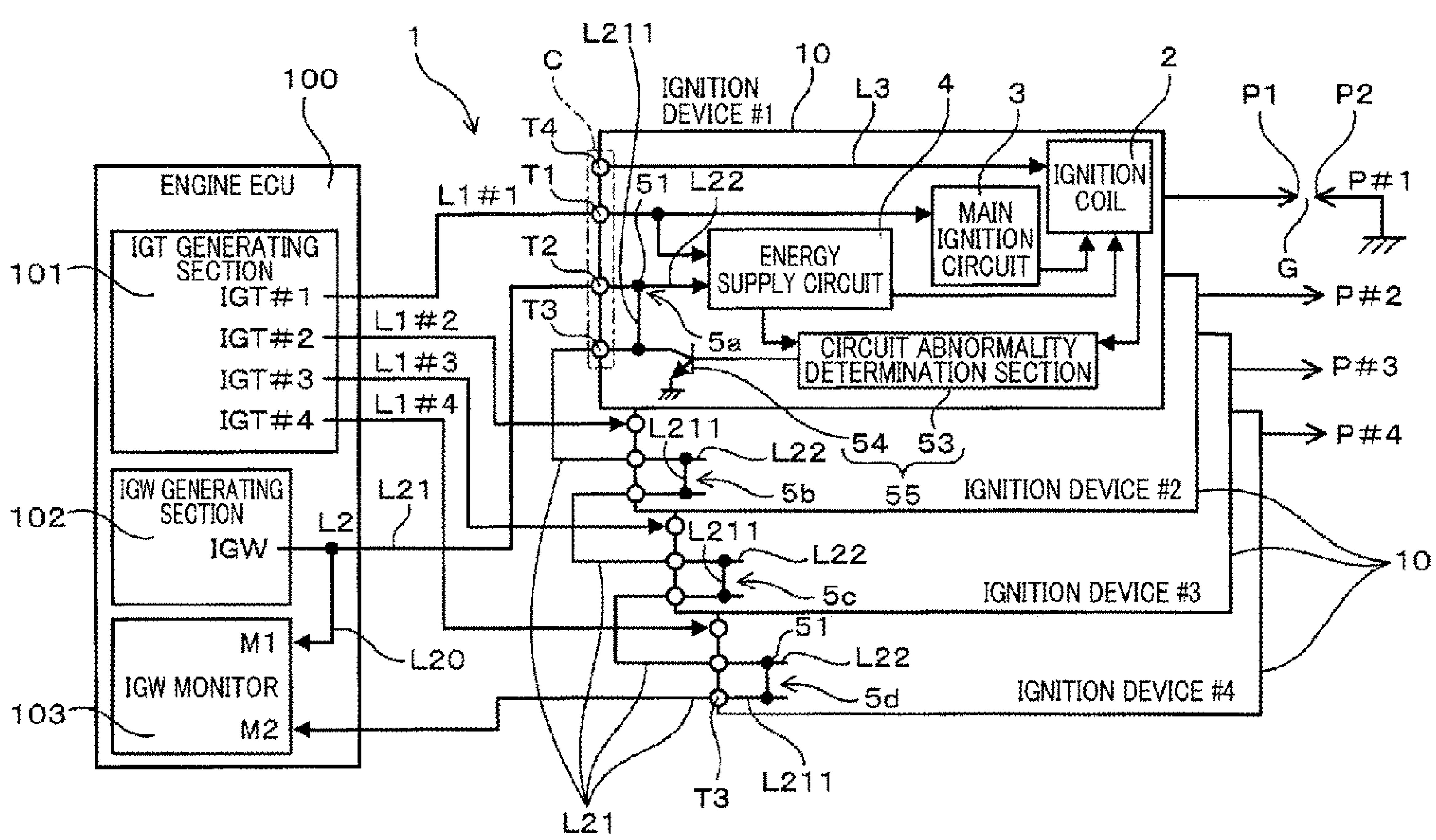
(57) **ABSTRACT**

An ignition control system for an internal combustion engine includes a controller, which includes an IGT generating section and an IGW generating section and is connected to ignition devices through an IGT signal line and an IGW signal line. The IGW signal line includes bifurcated portions, which sequentially bifurcate from a common main signal line. The bifurcated portions each correspond to one of the ignition devices and include a branched line, which is connected to an energy supply circuit inside the corresponding ignition device.

7 Claims, 8 Drawing Sheets



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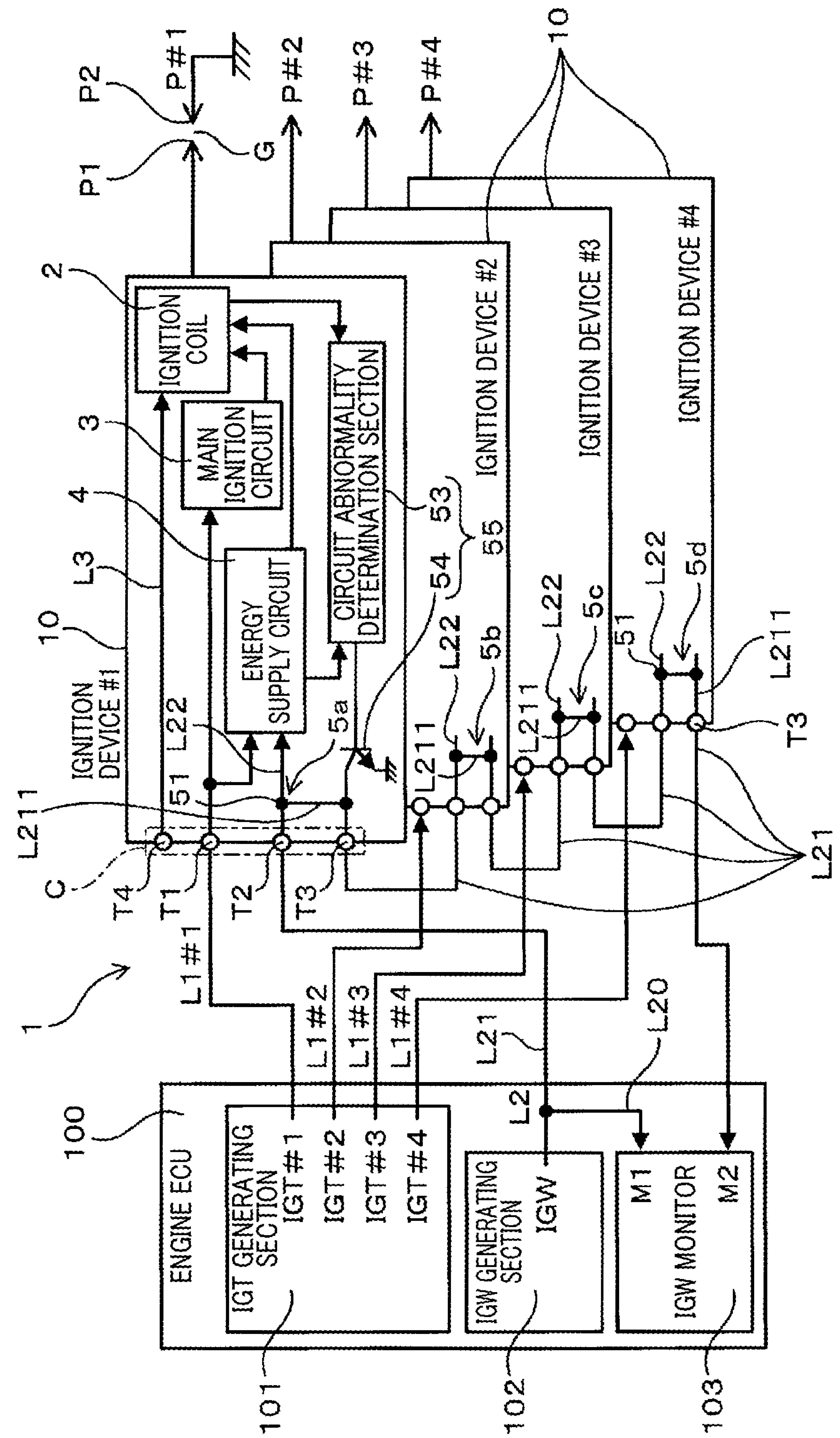

ENGINE ECU
IGT GENERATING SECTION
IGT#1
IGT#2
IGT#3
IGT#4
IGW GENERATING SECTION
IGW
IGW MONITOR
M1
M2
IGNITION DEVICE #1
IGNITION DEVICE #2
IGNITION DEVICE #3
IGNITION DEVICE #4
IGNITION COIL
MAIN IGNITION CIRCUIT
ENERGY SUPPLY CIRCUIT
CIRCUIT ABNORMALITY DETERMINATION SECTION
P#1
P#2
P#3
P#4
P1
P2
G
L1#1
L1#2
L1#3
L1#4
L2
L20
L21
L22
L211
L3
T1
T2
T3
T4
C
1
2
3
4
10
51
53
54
55
5a
5b
5c
5d
100
101
102
103

FIG. 1

FIG.2

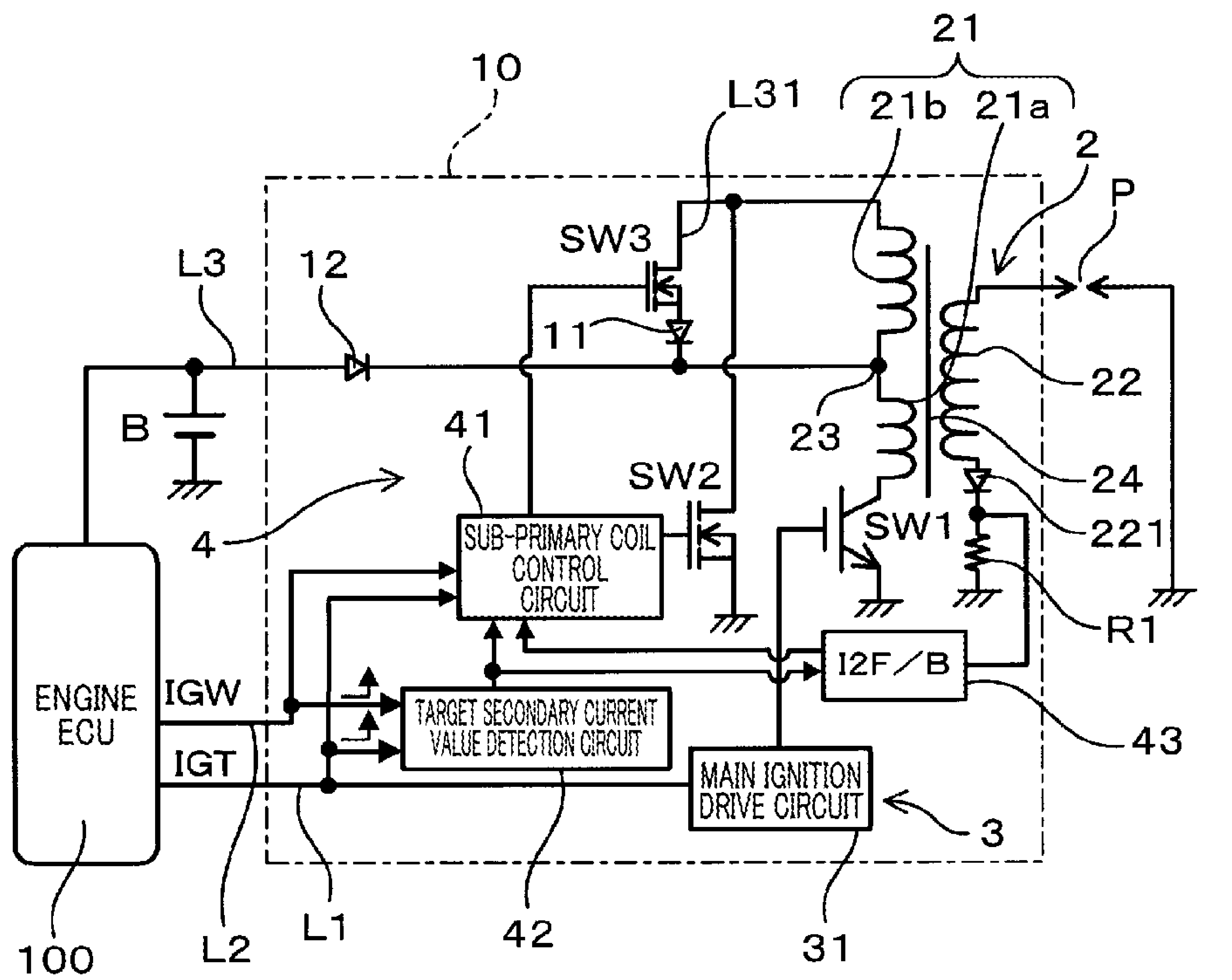

10
L31
21
21b 21a
2
P
SW3
L3
12
11
22
B
41
23
SW2
24
4
SW1
221
SUB-PRIMARY COIL CONTROL CIRCUIT
R1
ENGINE ECU
IGW
TARGET SECONDARY CURRENT VALUE DETECTION CIRCUIT
I2F/B
43
IGT
MAIN IGNITION DRIVE CIRCUIT
3
100
L2
L1
42
31

FIG.3

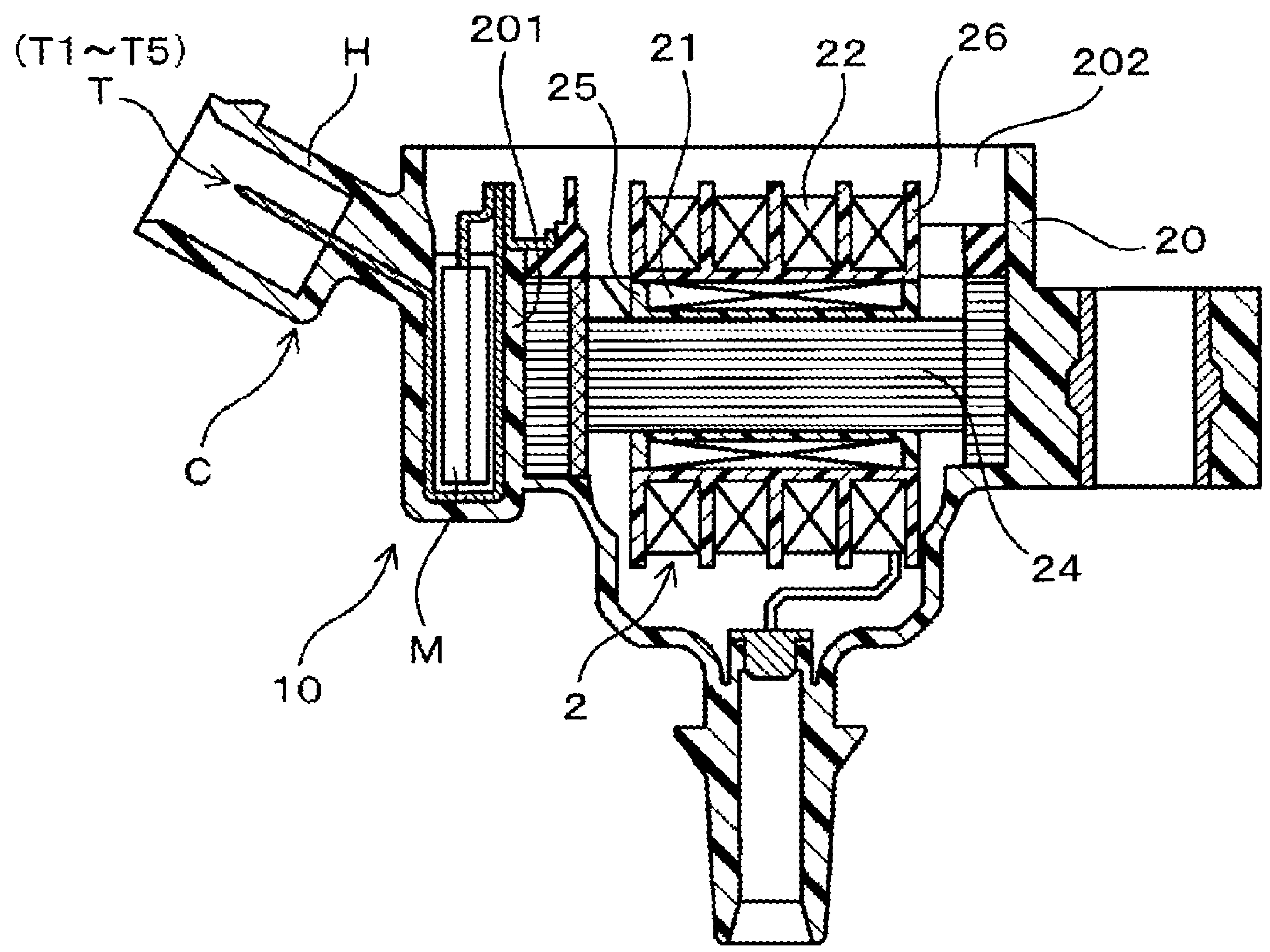

(T1~T5)
T
H
201
25
21
22
26
202
20
C
24
10
M
2

FIG.4

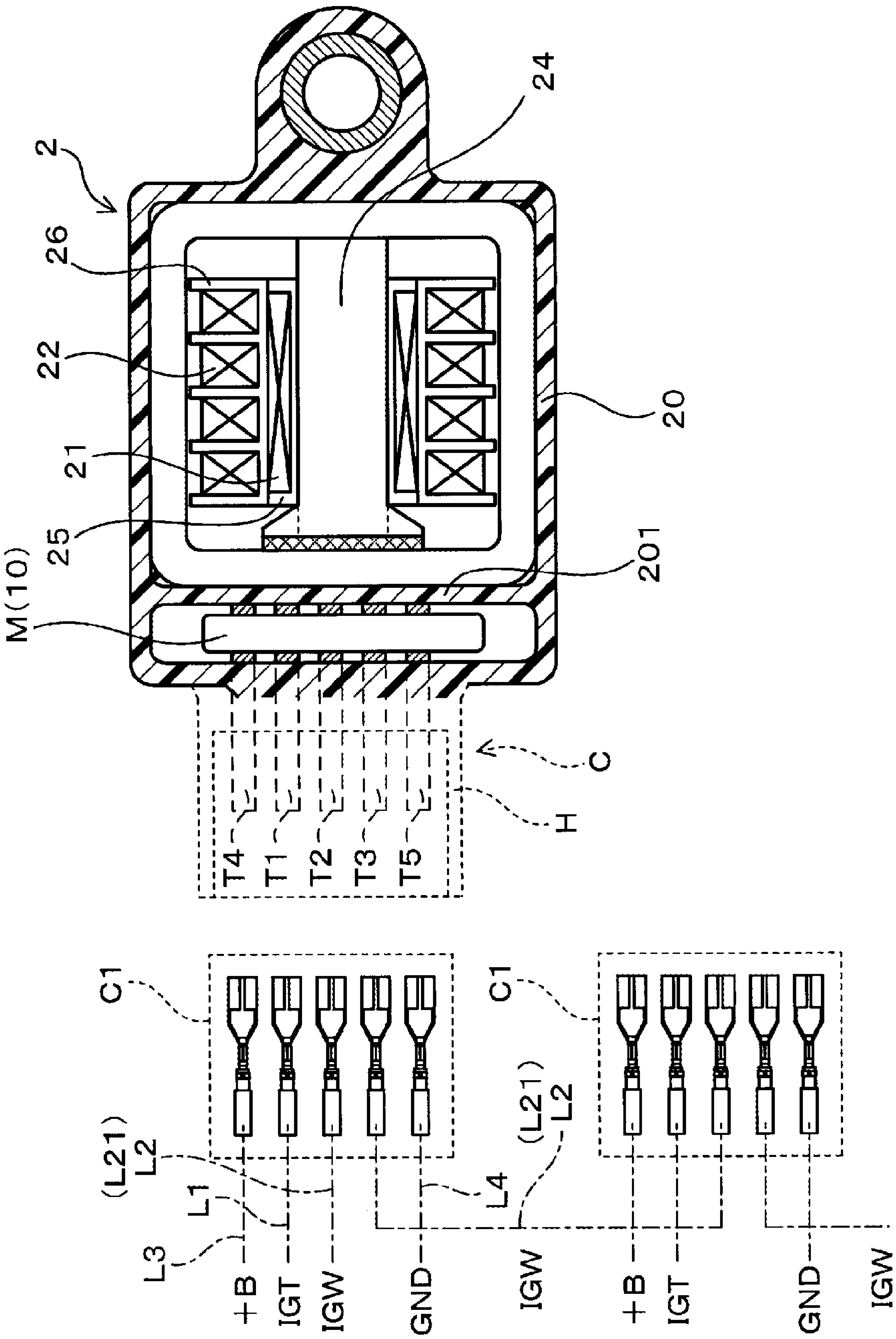
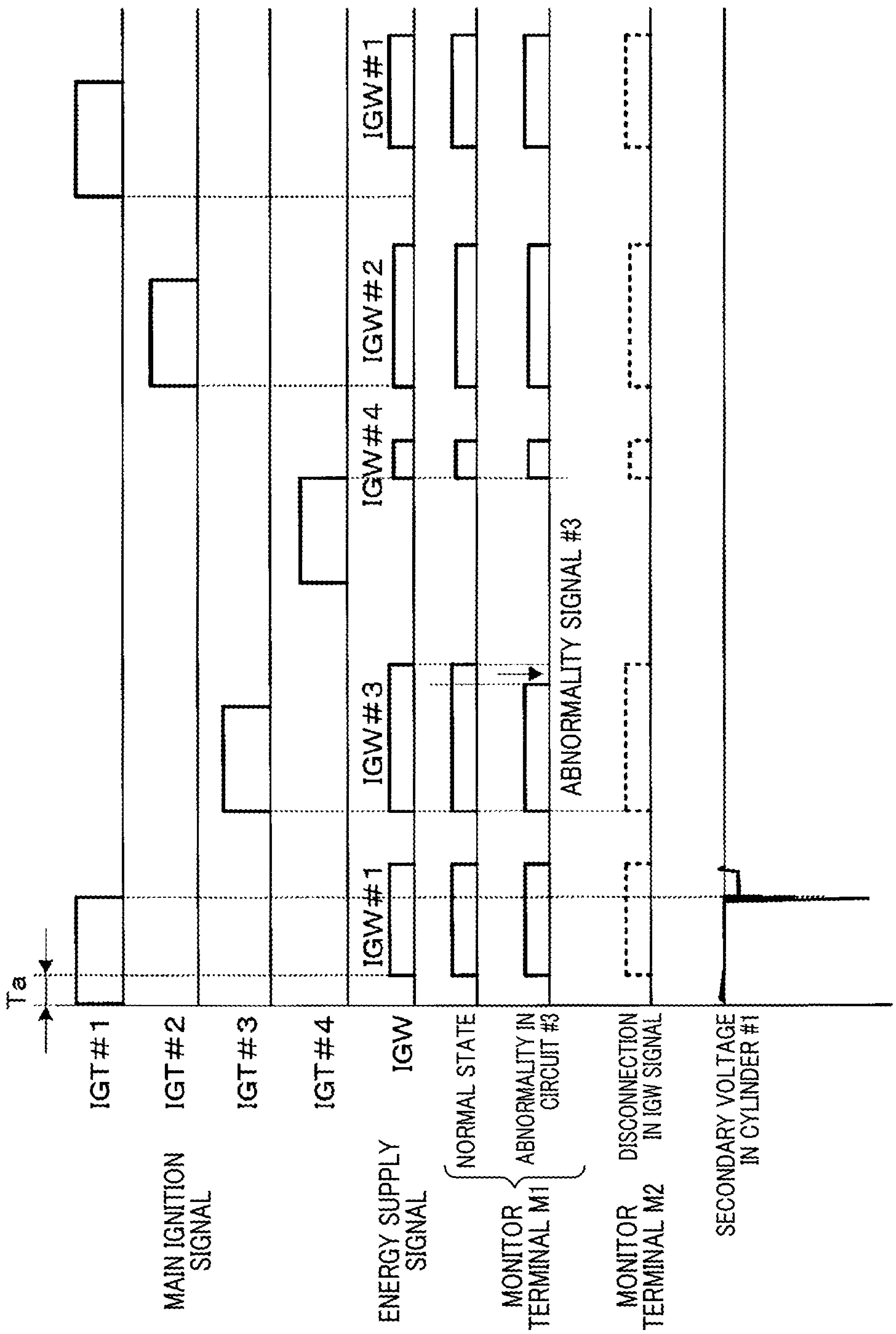

2
26
22
21
25
M(10)
24
20
201
C
H
T4
T1
T2
T3
T5
C1
C1
L3
L1
L2
(L21)
L4
L2
(L21)
+B
IGT
IGW
GND
IGW
+B
IGT
GND
IGW

FIG.5



Ta
MAIN IGNITION SIGNAL
IGT#1
IGT#2
IGT#3
IGT#4
ENERGY SUPPLY SIGNAL
IGW
IGW#1
IGW#3
IGW#4
IGW#2
IGW#1
MONITOR TERMINAL M1
NORMAL STATE
ABNORMALITY IN CIRCUIT #3
ABNORMALITY SIGNAL #3
MONITOR TERMINAL M2
DISCONNECTION IN IGW SIGNAL
SECONDARY VOLTAGE IN CYLINDER #1

FIG.6

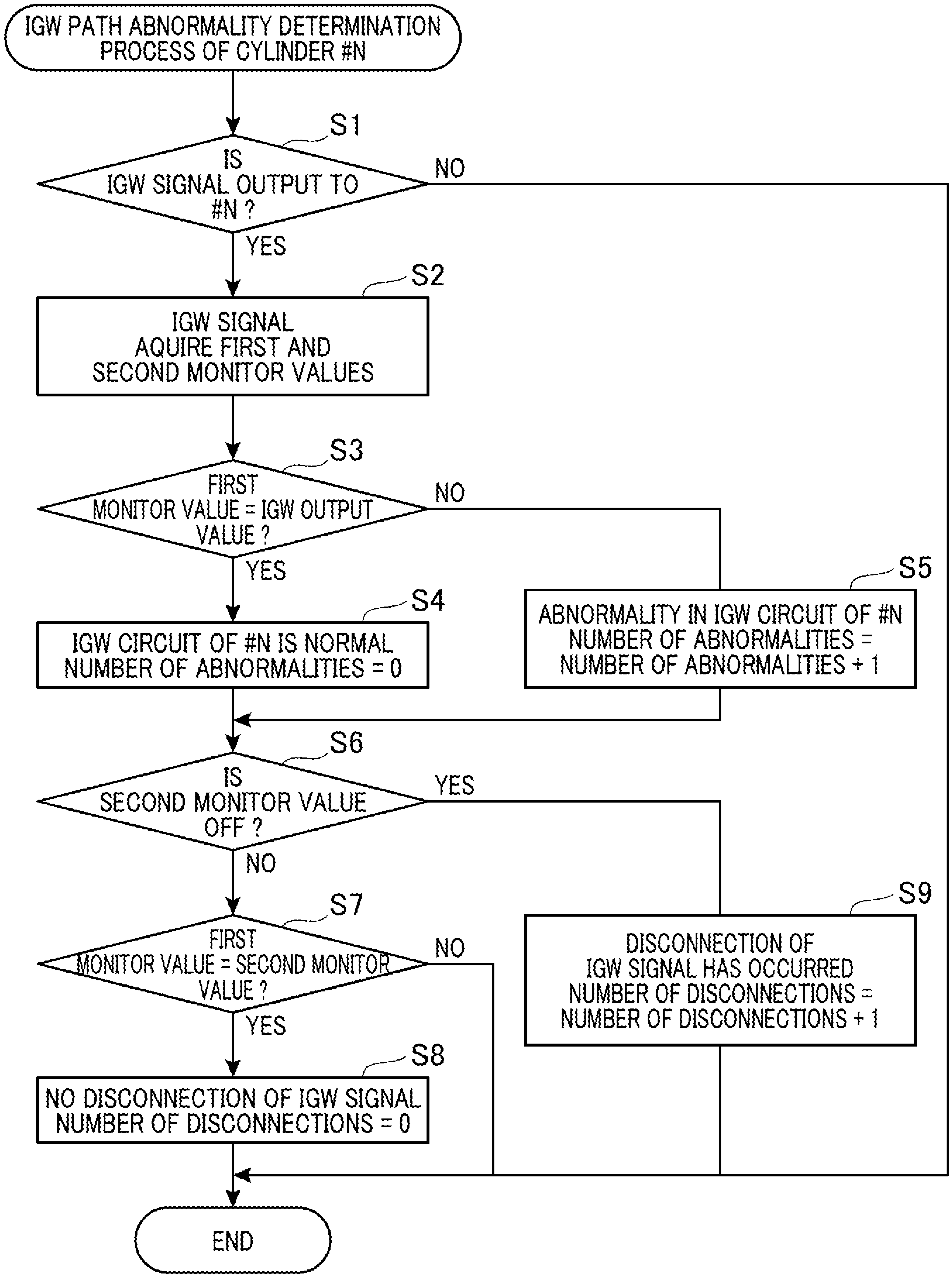

IGW PATH ABNORMALITY DETERMINATION PROCESS OF CYLINDER #N
S1
IS IGW SIGNAL OUTPUT TO #N ?
NO
YES
S2
IGW SIGNAL AQUIRE FIRST AND SECOND MONITOR VALUES
S3
FIRST MONITOR VALUE = IGW OUTPUT VALUE ?
NO
YES
S4
IGW CIRCUIT OF #N IS NORMAL
NUMBER OF ABNORMALITIES = 0
S5
ABNORMALITY IN IGW CIRCUIT OF #N
NUMBER OF ABNORMALITIES = NUMBER OF ABNORMALITIES + 1
S6
IS SECOND MONITOR VALUE OFF ?
YES
NO
S7
FIRST MONITOR VALUE = SECOND MONITOR VALUE ?
NO
YES
S8
NO DISCONNECTION OF IGW SIGNAL
NUMBER OF DISCONNECTIONS = 0
S9
DISCONNECTION OF IGW SIGNAL HAS OCCURRED
NUMBER OF DISCONNECTIONS = NUMBER OF DISCONNECTIONS + 1
END

FIG.7

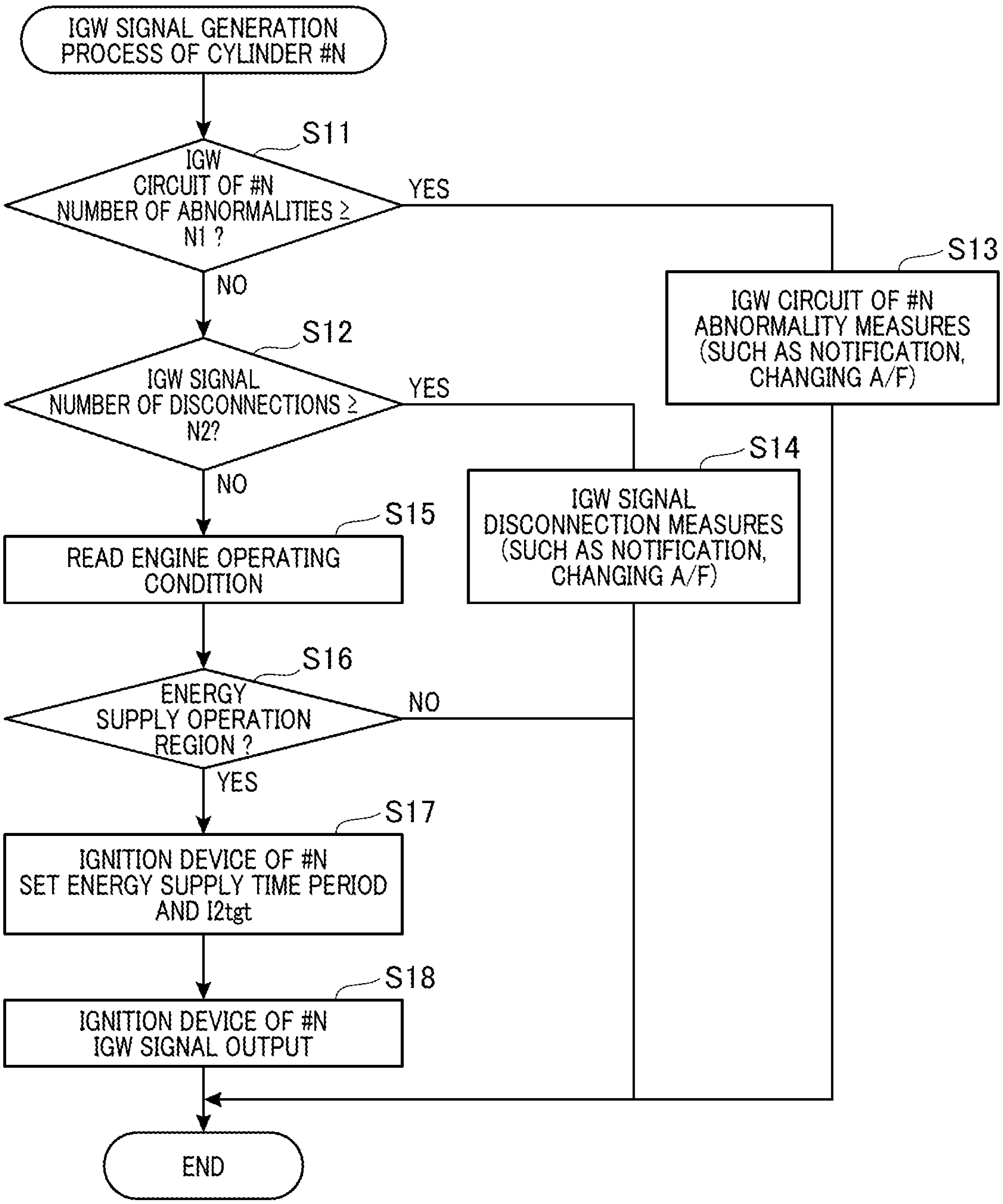

IGW SIGNAL GENERATION PROCESS OF CYLINDER #N
S11
IGW CIRCUIT OF #N NUMBER OF ABNORMALITIES ≥ N1 ?
YES
NO
S13
IGW CIRCUIT OF #N ABNORMALITY MEASURES (SUCH AS NOTIFICATION, CHANGING A/F)
S12
IGW SIGNAL NUMBER OF DISCONNECTIONS ≥ N2?
YES
NO
S14
IGW SIGNAL DISCONNECTION MEASURES (SUCH AS NOTIFICATION, CHANGING A/F)
S15
READ ENGINE OPERATING CONDITION
S16
ENERGY SUPPLY OPERATION REGION ?
NO
YES
S17
IGNITION DEVICE OF #N SET ENERGY SUPPLY TIME PERIOD AND I2tgt
S18
IGNITION DEVICE OF #N IGW SIGNAL OUTPUT
END

FIG.8

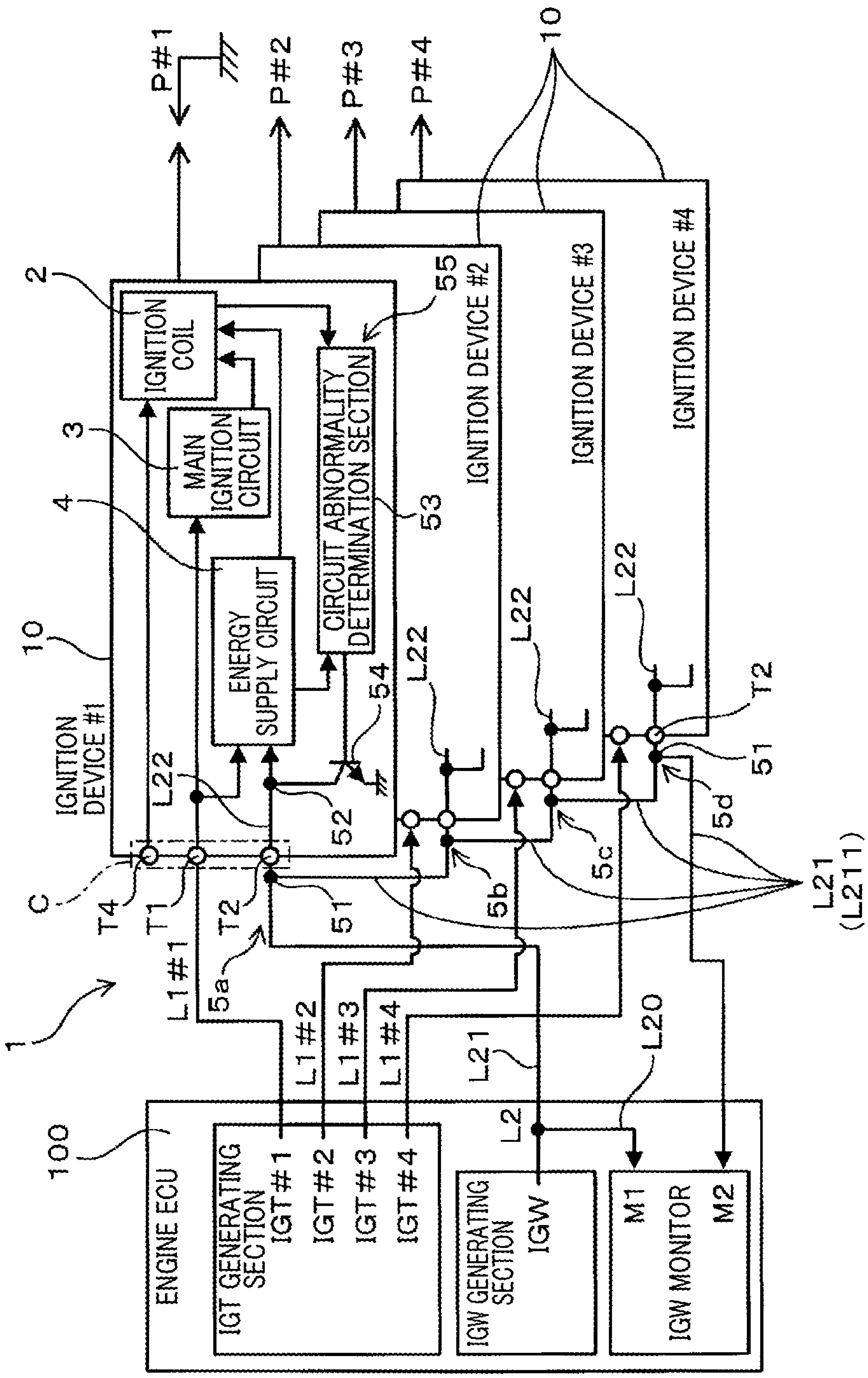

P#1
P#2
P#3
P#4
10
2
IGNITION COIL
3
MAIN IGNITION CIRCUIT
4
ENERGY SUPPLY CIRCUIT
CIRCUIT ABNORMALITY DETERMINATION SECTION
55
53
54
IGNITION DEVICE #1
IGNITION DEVICE #2
IGNITION DEVICE #3
IGNITION DEVICE #4
L22
52
C
T4
T1
T2
51
5a
5b
5c
5d
L21
(L211)
1
L1#1
L1#2
L1#3
L1#4
L21
L20
L2
100
ENGINE ECU
IGT GENERATING SECTION
IGT#1
IGT#2
IGT#3
IGT#4
IGW GENERATING SECTION
IGW
M1
IGW MONITOR
M2

FIG.9

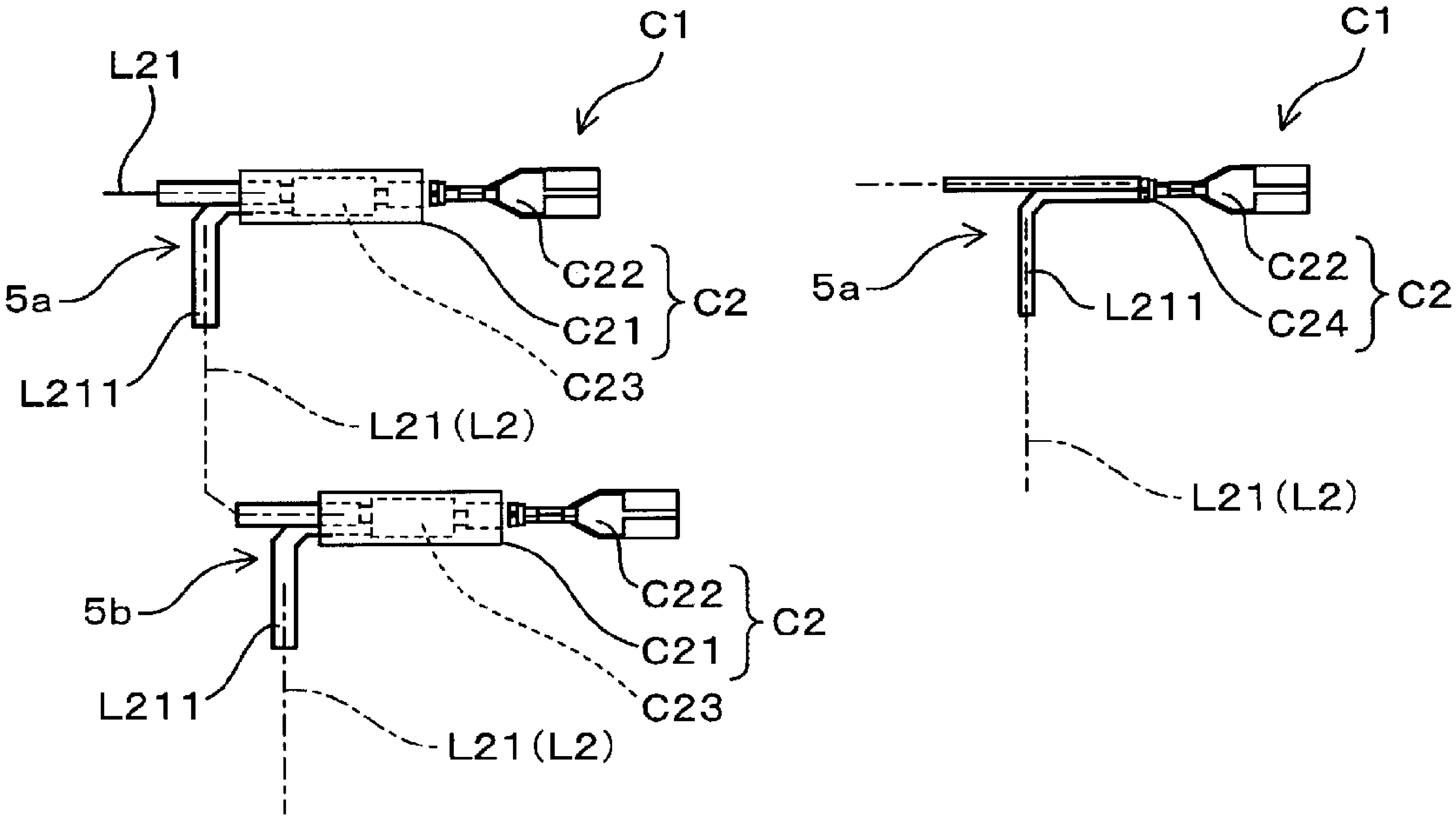
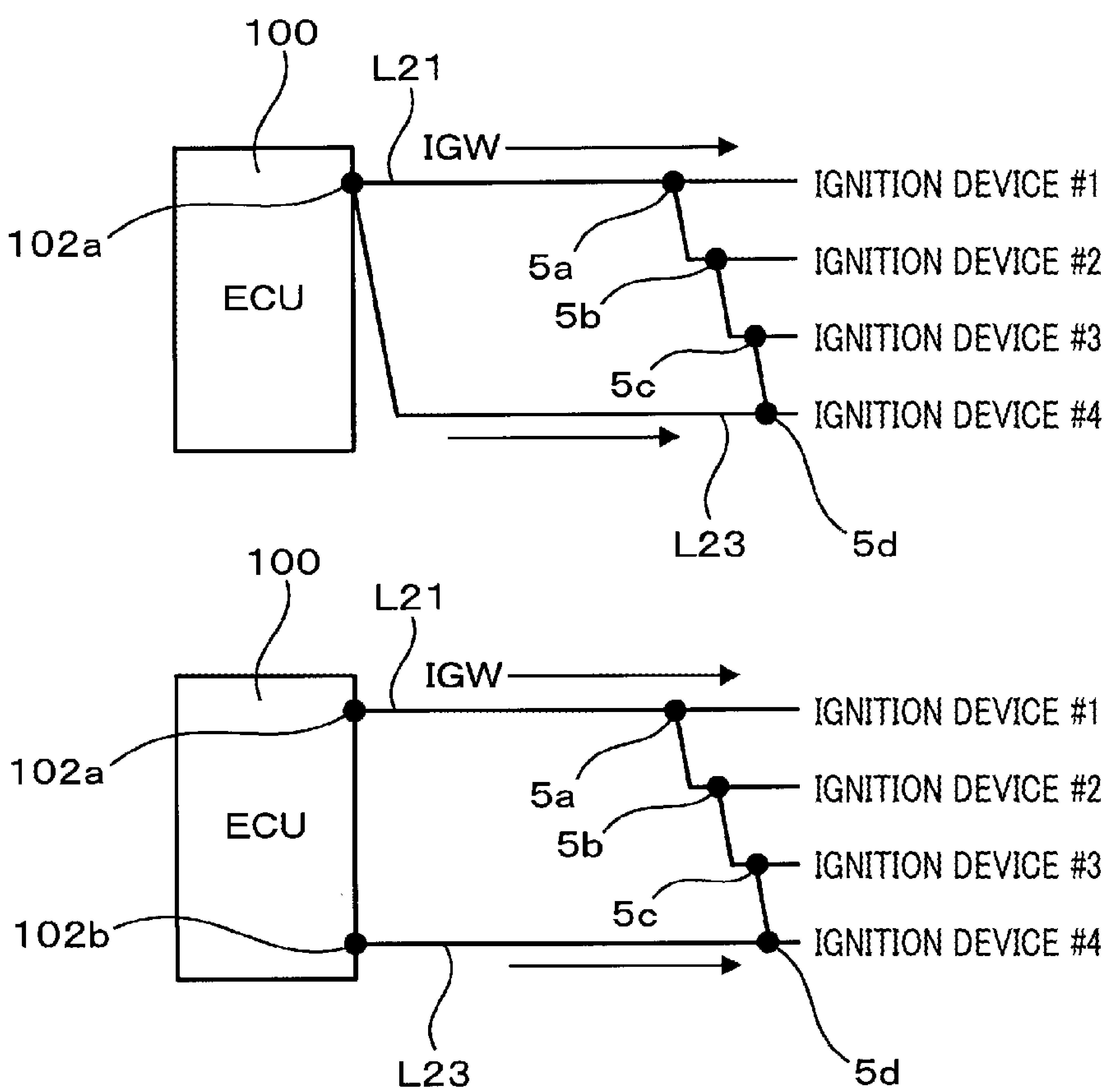

C1
L21
5a
L211
C22
C21
C2
C23
L21(L2)
5b
C24

FIG.10


100
L21
IGW
102a
ECU
102b
IGNITION DEVICE #1
IGNITION DEVICE #2
IGNITION DEVICE #3
IGNITION DEVICE #4
5a
5b
5c
5d
L23

IGNITION CONTROL SYSTEM FOR INTERNAL COMBUSTION ENGINE

CROSS-REFERENCE TO RELATED APPLICATION

This application is the U.S. bypass application of International Application No. PCT/JP2019/023179 filed on Jun. 12, 2019 which designated the U.S. and claims priority to Japanese Patent Application No. 2018-116070 filed on Jun. 19, 2018, the contents of both of which are incorporated herein by reference.

TECHNICAL FIELD

The present disclosure relates to an ignition control system for controlling ignition of an internal combustion engine.

BACKGROUND

Ignition control systems for spark ignition vehicle engines include ignition devices. Each ignition device includes an ignition coil, which includes a primary coil and a secondary coil. The ignition coil is connected to an ignition plug provided for each cylinder. A high voltage generated in the secondary coil by interruption of current supply to the primary coil is applied to the ignition plug, so that a spark discharge is caused. Additionally, ignition devices have been proposed that are capable of continuing the spark discharge with means for supplying discharge energy after start of the spark discharge in order to improve the ignitability to the air-fuel mixture by the spark discharge.

Multiple ignitions can be performed by a single ignition coil by repeating the ignition operation. However, to control the ignition in a more stable manner, an ignition device has been proposed that adds discharge energy during the spark discharge caused by the main ignition operation to increase the secondary current in a superimposed manner. For example, International Publication 2017/010310 proposes an ignition device that is provided with two systems of ignition energy supply means per each cylinder. The electrical discharge performed by the ignition energy supply means of one of the systems and the electrical discharge performed by the ignition energy supply means of the other system are superimposed on each other and output.

An ignition device disclosed in International Publication 2017/010310 includes, for example, two sets of ignition coils as the two systems of the ignition energy supply means. After the main ignition performed by one of the ignition coils, the secondary current is supplied in the same direction continuously using the other ignition coil. Thus, the spark discharge is continued in the same direction, which improves the ignitability. The signal indicating the point in time for supplying energy after the main ignition is transmitted through the signal line common to the cylinders. Thus, the energy is supplied regardless of the number of cylinders of the engine. Additionally, an abnormality in the other ignition coil is detected by monitoring the signal level of the common signal line.

SUMMARY

One aspect of the present disclosure provides an ignition control system for an internal combustion engine including ignition devices corresponding to cylinders of the internal combustion engine and a controller, which outputs signals for controlling the ignition devices. Each ignition device includes an ignition coil, which generates discharge energy in a secondary coil connected to an ignition plug by an increase and decrease in a primary current that flows through a primary coil, a main ignition circuit, which controls current supply to the primary coil to perform a main ignition operation that causes a spark discharge at the ignition plug, and an energy supply circuit, which performs an energy supply operation that superimposes current on a secondary current that flows through the secondary coil by the main ignition operation. The controller includes an IGT generating section, which generates a main ignition signal for controlling the main ignition operation, and an IGW generating section, which generates an energy supply signal for controlling the energy supply operation. The controller is connected to the ignition devices through an IGT signal line for transmitting the main ignition signal and an IGW signal line for transmitting the energy supply signal. The IGW signal line includes a common main signal line having one end connected to the controller and bifurcated portions, which sequentially bifurcate from the main signal line. The bifurcated portions each correspond to one of the ignition devices and include a branched line, which is connected to the energy supply circuit inside the corresponding ignition device. The bifurcated portions each include a main line, which forms a pair with the branched line, and the main lines are connected in series with each other and form a part of the main signal line. The controller includes an IGW monitor, which is connected to a signal path of the IGW signal line and monitors the energy supply signal. The IGW monitor receives a signal from the main line of the bifurcated portion that branches last from the main signal line, which serves as a distal end of the signal path of the IGW signal line, and the IGW monitor compares the signal input from the distal end with the energy supply signal output to one end of the main signal line from the IGW generating section to determine whether there is an abnormality.

BRIEF DESCRIPTION OF THE DRAWINGS

The above features of the present disclosure will be made clearer by the following detailed description, given referring to the appended drawings. In the accompanying drawings:

FIG. **1** is a schematic diagram illustrating the entire configuration of an ignition control system for an internal combustion engine according to a first embodiment;

FIG. **2** is a circuit diagram illustrating an exemplary ignition device used in the ignition control system for the internal combustion engine according to the first embodiment;

FIG. **3** is a vertical cross-sectional view of the ignition device constituting the ignition control system according to the first embodiment;

FIG. **4** is a diagram illustrating the connection structure of signal lines in a transverse cross-sectional view of the ignition device constituting the ignition control system according to the first embodiment;

FIG. **5** is a timing chart showing the relationship between various signals generated by a controller of the ignition control system, the ignition operation of the ignition devices, and signals input to an IGW monitor of the controller according to the first embodiment;

FIG. **6** is a flowchart of an abnormality determination process performed by the controller constituting the ignition control system according to the first embodiment;

FIG. **7** is a control flowchart of an energy supply operation performed by the controller of the ignition control system according to the first embodiment;

FIG. **8** is a schematic diagram illustrating the entire configuration of an ignition control system for an internal combustion engine according to a second embodiment;

FIG. **9** is a schematic diagram illustrating a connecting terminal of an IGW signal line showing an exemplary configuration of the connection end between the IGW signal line and the ignition device according to the second embodiment; and

FIG. **10** is a schematic diagram illustrating an exemplary connection structure of a signal line between a controller of an ignition control system and an ignition device according to a third embodiment.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

In International Publication 2017/010310, the common signal line for supplying energy to the ignition devices includes one end connected to the engine controller and the other end branching in the middle by the number of cylinders. Each branched signal line is connected to the ignition device of the corresponding cylinder. With this configuration, control signals for supplying energy to multiple ignition devices can be output by adding one signal line to the engine controller. However, when actually mounting a wire harness in which one signal line has multiple branches, the following problem arises.

To make branches on the common signal line in the middle, specifically, it is necessary to connect different signal lines to the end of one signal line by, for example, soldering or using crimped terminals. Although it is generally preferred to make multiple branches at a single location to reduce the number of man-hours, if the number of cylinders is increased, the number of connecting lines at the branched portion of the signal line is increased, which is likely to decrease the reliability in the connection. Integrating multiple signal lines not only increases the size of the branched portion, but also increases the rigidity. This decreases the degree of freedom in mounting the wire harness in the vehicle.

It is an object of the present disclosure to provide a small, highly reliable ignition control system for an internal combustion engine. The structure for supplying energy to ignition devices using a common signal line has improved connection reliability at branched portions of the signal line and inhibits an increase in the size and a decrease in the flexibility of the branched portions, so that the degree of freedom in mounting the signal line is improved.

One aspect of the present disclosure provides an ignition control system for an internal combustion engine including ignition devices corresponding to cylinders of the internal combustion engine and a controller, which outputs signals for controlling the ignition devices. Each ignition device includes an ignition coil, which generates discharge energy in a secondary coil connected to an ignition plug by an increase and decrease in a primary current that flows through a primary coil, a main ignition circuit, which controls current supply to the primary coil to perform a main ignition operation that causes a spark discharge at the ignition plug, and an energy supply circuit, which performs an energy supply operation that superimposes current on a secondary current that flows through the secondary coil by the main ignition operation. The controller includes an IGT generating section, which generates a main ignition signal for controlling the main ignition operation, and an IGW generating section, which generates an energy supply signal for controlling the energy supply operation. The controller is connected to the ignition devices through an IGT signal line for transmitting the main ignition signal and an IGW signal line for transmitting the energy supply signal. The IGW signal line includes a common main signal line having one end connected to the controller and bifurcated portions, which sequentially bifurcate from the main signal line. The bifurcated portions each correspond to one of the ignition devices and include a branched line, which is connected to the energy supply circuit inside the corresponding ignition device. The bifurcated portions each include a main line, which forms a pair with the branched line, and the main lines are connected in series with each other and form a part of the main signal line. The controller includes an IGW monitor, which is connected to a signal path of the IGW signal line and monitors the energy supply signal. The IGW monitor receives a signal from the main line of the bifurcated portion that branches last from the main signal line, which serves as a distal end of the signal path of the IGW signal line, and the IGW monitor compares the signal input from the distal end with the energy supply signal output to one end of the main signal line from the IGW generating section to determine whether there is an abnormality.

In the ignition control system, the ignition devices perform the main ignition operation in accordance with the main ignition signal transmitted from the controller and further perform the energy supply operation in accordance with the energy supply signal. The IGW signal line for transmitting the energy supply signal has a compact structure in which the bifurcated portions sequentially branch from the common main signal line and has improved reliability in the connection of the bifurcated portions that branch from the main signal line.

Since the branches do not concentrate are not concentrated at one location of the common main signal line, an increase in the size of the branched portions and a decrease in the flexibility are inhibited, so that the degree of freedom in mounting the wire harness is improved. This inhibits the increase in the mounting space in the vehicle, and the limited space in the vehicle is efficiently used. Furthermore, an abnormality such as a disconnection is detected by, for example, monitoring signals at multiple locations in the common main signal line, which increases the reliability of the system.

As described above, the above aspect provides a small, highly reliable ignition control system for an internal combustion engine. The structure for supplying energy to ignition devices using a common signal line has improved connection reliability at branched portions of the signal line and inhibits an increase in the size and a decrease in the flexibility of the branched portions, so that the degree of freedom in mounting the signal line is improved.

First Embodiment

An ignition control system for an internal combustion engine according to a first embodiment will be described with reference to FIGS. **1** to **7**.

In FIG. **1**, an ignition control system **1** is applied to, for example, a spark ignition engine for vehicles and controls the ignition of an ignition plug P provided for each cylinder. The ignition control system **1** includes ignition devices **10** corresponding to cylinders of a non-illustrated engine and a controller, which outputs signals for controlling the ignition devices **10**. The controller is an electronic control unit for an engine (hereinafter, simply referred to as an engine ECU **100**).

The ignition devices **10** each include an ignition coil **2**, a main ignition circuit **3**, and an energy supply circuit **4**. As shown by an exemplary configuration in FIG. **2**, each ignition coil **2** generates discharge energy in a secondary coil **22**, which is connected to the associated ignition plug P, in accordance with an increase or a decrease in a primary current I**1** that flows through a primary coil **21**. The main ignition circuit **3** controls current supply to the primary coil **21** to perform a main ignition operation that causes a spark discharge at the ignition plug P. The energy supply circuit **4** performs an energy supply operation that superimposes a current on a secondary current I**2** that flows through the secondary coil **22** by the main ignition operation.

The engine ECU **100** includes an IGT generating section **101**, which generates main ignition signals IGT for controlling the ignition operation, and an IGW generating section **102**, which generates energy supply signals IGW for controlling the energy supply operation. The engine ECU **100** is connected to the ignition devices **10** through IGT signal lines L**1** for transmitting the main ignition signals IGT and an IGW signal line L**2** for transmitting the energy supply signals IGW. This configuration enables the main ignition signals IGT generated in the IGT generating section **101** and the energy supply signals IGW generated in the IGW generating section **102** to be transmitted to the ignition devices **10** at their respective predetermined point in time.

The IGW signal line L**2** includes a common main signal line L**21**, one end of which is connected to the engine ECU **100**, and bifurcated portions **5***a* to **5***d*, which are sequentially bifurcated from the main signal line L**21**. The bifurcated portions **5***a* to **5***d* each correspond to one of the ignition devices **10** and include a branched line L**22**, which is connected to the energy supply circuit **4** inside the corresponding ignition device **10**.

More specifically, the bifurcated portions **5***a* to **5***d* each include a main line L**211**, which forms a pair with the associated branched line L**22**. The main lines L**211** are connected in series with each other and constitute part of the main signal line L**21**. The branching position of each of the bifurcated portions **5***a* to **5***d* is desirably located inside the corresponding ignition device **10** or at the end connected to the corresponding ignition device **10**.

Each ignition device **10** preferably includes a connector section C, which includes an IGT input terminal T**1**, an IGW input terminal T**2**, and an IGW output terminal T**3**. The IGT signal line L**1** is connected to the IGT input terminal T**1**. The main signal line L**21** is connected to the IGW input terminal T**2** and the IGW output terminal T**3**. Each of the bifurcated portions **5***a* to **5***d* is located inside the associated ignition device **10** between the IGW input terminal T**2** and the energy supply circuit **4**. The main line L**211** is connected to the IGW output terminal T**3** to be drawn out of the ignition device **10**.

Each ignition device **10** includes a signal level holding section **55**, which holds the level of the signal of the main signal line L**21** to an off state when an abnormality is detected in the energy supply circuit **4**.

Furthermore, the engine ECU **100** includes an IGW monitor **103**, which is connected to a signal path of the IGW signal line L**2** and monitors the energy supply signals IGW.

The IGW monitor **103** receives, for example, a signal from the main line L**211** of the bifurcated portion **5***d*, which branches last from the main signal line L**21** and serves as the distal end of the signal path of the IGW signal line L**2**. The IGW monitor **103** determines the presence/absence of an abnormality by comparing the signal input from the distal end with the energy supply signal IGW output to one end of the main signal line L**21** from the IGW generating section **102**.

Hereinafter, the ignition devices **10** and the engine ECU **100**, which constitute the ignition control system **1**, will be described in detail.

The engine to which the ignition control system **1** of the present embodiment is applied is, for example, a four-cylinder engine (hereinafter, the cylinders will be referred to as cylinders #1 to #4) and includes the ignition plugs P (for example, indicated as P #1 to P #4 in FIG. **1**) corresponding to the cylinders and the ignition devices **10** (for example, indicated as **10** #1 to **10** #4 in FIG. **1**) corresponding to the ignition plugs P. In this embodiment, four ignition devices **10** are provided in accordance with the number of the cylinders. The main ignition signal IGT and the energy supply signal IGW are transmitted to each ignition device **10** from the engine ECU **100** to control current supply to the associated ignition coil **2**.

The ignition plug P has a known structure and includes a center electrode P**1** and a ground electrode P**2**, which face each other. The space formed between the distal ends of the electrodes is a spark gap G. The ignition device **10** activates the main ignition circuit **3** in response to the main ignition signal IGT and performs the main ignition operation on the ignition plug P. More specifically, when the discharge energy generated in the ignition coil **2** in response to the main ignition signal IGT is supplied, a spark discharge occurs in the spark gap G, allowing the air-fuel mixture in the non-illustrated engine combustion chamber to be ignited. After the main ignition, the energy supply circuit **4** of the ignition device **10** is activated in response to the energy supply signal IGW to perform an operation to supply energy to the ignition coil **2**, so that the spark discharge is continued.

The engine ECU **100** generates the main ignition signal IGT for each cylinder (for example, indicated as IGT #1 to IGT #4 in FIG. **1**) in the IGT generating section **101** and transmits it to the ignition device **10** of the corresponding cylinder through the IGT signal line L**1** for each cylinder (for example, indicated as L**1** #1 to L**1** #4 in FIG. **1**). Additionally, the engine ECU **100** generates the energy supply signal IGW corresponding to each cylinder (for example, indicated as IGW #1 to IGW #4 in FIG. **5**) in the IGW generating section **102** and transmits it to the cylinder through the IGW signal line L**2**, which includes the common main signal line L**21**.

The engine ECU **100** includes the IGW monitor **103** and monitors the transmitted energy supply signal IGW at, for example, multiple locations to detect an output abnormality of the energy supply signal IGW, a disconnection of the IGW signal line L**2**, or an abnormality in the operation or the circuit of the energy supply circuit **4** of each ignition device **10**. In the present embodiment, the IGW monitor **103** includes a first monitor terminal M**1** and a second monitor terminal M**2**.

The connector section C of each ignition device **10** includes the IGT input terminal T**1**, to which the IGT signal line L**1** is connected, and the IGW input terminal T**2** and the IGW output terminal T**3**, to which the IGW signal line L**2** is connected. Four IGT signal lines L**1** (L**1** #1 to L**1** #4) of the cylinders each include one end connected to the IGT generating section **101** and the other end connected to the main ignition circuit **3** and the energy supply circuit **4** inside the ignition device **10** of each cylinder.

The connector section C also includes a supply terminal T**4**, which is connected to a non-illustrated power supply, and current can be supplied to the ignition coil **2** through a supply line L**3**. Besides these terminals, the connector section C includes a non-illustrated ground terminal T**5**.

One end of the main signal line L**21** of the IGW signal line L**2** is connected to the IGW generating section **102**, and the other end sequentially passes through the inside of the four ignition devices **10** via the IGW input terminals T**2** and the IGW output terminals T**3** of the ignition devices **10**. The branched lines L**22** bifurcate from the main signal line L**21** one after the other inside the ignition devices **10** to form the bifurcated portions **5***a* to **5***d*.

The common main signal line L**21** located between the IGW generating section **102** and the four ignition devices **10** is first connected to the IGW input terminal T**2** of one of the four ignition devices **10** (for example, the ignition device #1 corresponding to the cylinder #1) and bifurcates inside the ignition device **10** (#1 cylinder). One line connected to the branch point **51** at the bifurcated portion **5***a* is the branched line L**22** and is connected to the energy supply circuit **4**. The other line connected to the branch point **51** is the main line L**211**, which constitutes a pair with the branched line L**22**, and forms part of the main signal line L**21**. The main line L**211** is connected to the IGW output terminal T**3** and is drawn out to the outside.

On the outside of the ignition device **10** (#1), the main signal line L**21** drawn out from the IGW output terminal T**3** is connected to the IGW input terminal T**2** of another ignition device **10** (for example, the ignition device **10** #2 corresponding to the cylinder #2). Similarly, the bifurcated portion **5***b* is also formed inside the ignition device **10** (#2). One branch of the bifurcated portion **5***b* is connected to the energy supply circuit **4** as the branched line L**22**, and the other branch of the bifurcated portion **5***b* is connected to the IGW output terminal T**3** as the main line L**211** to be drawn out to the outside. Furthermore, the bifurcated portions **5***c* and **5***d*, which have the same configuration, are provided in the other ignition devices **10** (#3, #4).

In this manner, while passing through the inside of the four ignition devices **10** in the order of cylinder #1 to cylinder #4, the IGW signal line L**2** branches the bifurcated portions **5***a* to **5***d* one after the other inside the ignition devices **10** along the way. The main lines L**211** of the bifurcated portions **5***a* to **5***d* are series connected with each other through the main signal line L**21** located outside the ignition devices **10**, the IGW input terminals T**2**, and the IGW output terminals T**3** and form a signal path, which forms one continuous main signal line L**21**.

In each of the bifurcated portions **5***a* to **5***d*, the branched line L**22** branched from the main signal line L**21** is connected to the associated energy supply circuit **4**. Thus, the energy supply signal IGW that is the same as the one transmitted to the main signal line L**21** is input to the energy supply circuit **4** of each ignition device **10**. The energy supply circuit **4** can distinguish the energy supply signal IGW of each cylinder by, for example, a logical product with the main ignition signal IGT input through the IGT signal line L**1**. This allows the energy supply circuit **4** to perform the energy supply operation in response to the energy supply signal IGW.

The bifurcated portion **5***d*, which is bifurcated last from the main signal line L**21** of the IGW signal line L**2**, is formed inside the ignition device **10** of the cylinder #4. The main line L**211** of the bifurcated portion **5***d* is connected to the IGW output terminal T**3** to be drawn out to the outside and is connected to the second monitor terminal M**2** of the IGW monitor **103** through the main signal line L**21** that serves as the distal end of the IGW signal line L**2**. In the engine ECU **100**, a signal line L**20**, which branches from one end of the IGW signal line L**2**, is connected to the first monitor terminal M**1** of the IGW monitor **103**. Thus, the IGW monitor **103** is capable of comparing the energy supply signal IGW that is immediately after being output from the IGW generating section **102** with the signal that has passed through the four ignition devices **10** at the distal end of the main signal line L**21**.

If there is an abnormality such as a disconnection in the wiring connecting the engine ECU **100** to the ignition device **10** of the cylinder #4, or between the ignition devices **10** of the cylinders #1 to #4, or in the internal circuits of the ignition devices **10**, the signal input to the second monitor terminal M**2** does not match the energy supply signal IGW that has been output (for example, refer to IGW disconnection state in FIG. **5**). Thus, while monitoring the energy supply signal IGW on one end of the main signal line L**21** by the first monitor terminal M**1**, the IGW monitor **103** monitors the signal from the main signal line L**21** connected to the bifurcated portion **5***d*, which is the distal end of the signal path of the IGW signal line L**2**, by the second monitor terminal M**2**. Comparing the instruction from the engine ECU **100** with these signals enables detecting an abnormality such as a disconnection.

Each ignition device **10** includes a circuit abnormality determination section **53** and a switching element **54**, which constitute the signal level holding section **55**. For example, when an abnormality of some kind is detected in the operation of the energy supply circuit **4** by the circuit abnormality determination section **53**, the signal level holding section **55** drives the switching element **54** to hold the level of the signal of the main signal line L**21** to the off state (for example, L level).

The switching element **54** is a bipolar transistor such as an NPN transistor. Current is conducted or interrupted between the collector terminal and the emitter terminal by controlling the base current in accordance with a drive voltage input to the base terminal.

More specifically, at a position between the branch point **51** and the IGW output terminal T**3** of each of the bifurcated portions **5***a* to **5***d*, the switching element **54** is connected between the main line L**211** and the ground terminal and is switched on and off by the circuit abnormality determination section **53**. In a normal state, the switching element **54** is switched off, so that the path between the main line L**211** and the ground terminal is interrupted. The circuit abnormality determination section **53** monitors, for example, the secondary current I**2** subjected to the energy supply operation performed by the energy supply circuit **4** and the primary current I**1** of the ignition coil **2** when the energy supply signal IGW is input to determine the presence/absence of an abnormality. If an abnormality is detected, the circuit abnormality determination section **53** switches on the switching element **54**. When the signal level holding section **55** is operated upon detection of an abnormality, the main line L**211** is connected to the ground potential, so that the signal is held to the L level regardless of the instruction from the engine ECU **100** (for example, refer to IGW #3 in FIG. **5**). The holding of the signal to the L level is achieved by the combination of a logic circuit of the energy supply signal IGW and the main ignition signal IGT and a timer circuit so as to be restored before the energy supply signal IGW of the next cylinder is output.

In this case also, the IGW monitor **103** monitors the signal input to the second monitor terminal M**2** and compares the instruction from the engine ECU **100** with the signal input to the second monitor terminal M**2**. This enables determining the abnormality detection result of the energy supply circuit **4**.

The operation of the IGW monitor **103** will be described in detail below.

FIG. **2** shows an exemplary specific configuration of the ignition device **10**. The primary coil **21** of the ignition coil **2** may include, for example, a main primary coil **21***a* and a sub-primary coil **21***b*. In this case, the main ignition circuit **3** controls current supply to the main primary coil **21***a* to control the main ignition operation, and the energy supply circuit **4** controls current supply to the sub-primary coil **21***b* to control the energy supply operation.

The main primary coil **21***a* or the sub-primary coil **21***b*, which serves as the primary coil **21**, and the secondary coil **22** are magnetically coupled, so that the ignition coil **2** forms a known boost transformer. One end of the secondary coil **22** is connected to the center electrode P**1** of the ignition plug P, and the other end is grounded through a first diode **221** and a secondary current detection resistance RE The first diode **221** is located so that an anode terminal is connected to the secondary coil **22** and a cathode terminal is connected to the secondary current detection resistance R**1** to restrict the direction of the secondary current I**2** that flows through the secondary coil **22**.

The main primary coil **21***a* and the sub-primary coil **21***b* are series connected with each other and are connected in parallel to a DC power supply B such as a vehicle battery. More specifically, an intermediate tap **23** is located between a first end of the main primary coil **21***a* and a first end of the sub-primary coil **21***b*. The intermediate tap **23** is connected to the supply line L**3**, which extends to the DC power supply B. A second end of the main primary coil **21***a* is grounded through a switching element for main ignition (hereinafter, referred to as a main ignition switch) SW**1**, and a second end of the sub-primary coil **21***b* is grounded through a switching element for continuing discharge (hereinafter, referred to as a discharge continuing switch) SW**2**.

This allows the DC power supply B to be electrically connected to the main primary coil **21***a* or the sub-primary coil **21***b* when the main ignition switch SW**1** or the discharge continuing switch SW**2** is on.

Sufficiently increasing the turns ratio causes a predetermined high voltage corresponding to the turns ratio to be generated in the secondary coil **22**. The turns ratio is the ratio between the number of turns of the main primary coil **21***a* or the sub-primary coil **21***b*, which is the primary coil **21**, and the number of turns of the secondary coil **22**. The main primary coil **21***a* and the sub-primary coil **21***b* are wound so that the directions of the magnetic flux generated when current is supplied from the DC power supply B are opposite to each other, and the number of turns of the sub-primary coil **21***b* is set to be less than the number of turns of the main primary coil **21***a*. With this configuration, after a discharge occurs at the spark gap G of the ignition plug P by a voltage caused by the interruption of current supply to the main primary coil **21***a*, a superimposed magnetic flux is generated in the same direction by current supply to the sub-primary coil **21***b*, so that discharge energy is increased in a superimposed manner.

As shown in FIG. **3**, the ignition coil **2** is integrally formed by winding the primary coil **21** and the secondary coil **22** around, for example, a tubular primary coil bobbin **25** and a tubular secondary coil bobbin **26** located around a shaft-like core **24**. The ignition coil **2** is accommodated in a housing **20** together with a circuit module M, which constitutes the circuit of the ignition device **10**, and is sealed with an insulating resin **202** that fills the housing **20**. In the housing **20**, the ignition coil **2** and the circuit module M are separated by a partition **201**, and the connector section C is integrally provided on the outer wall of the housing **20** adjacent to the circuit module M. The connector section C includes a tubular housing H and connector terminals T, which are accommodated inside the housing H.

As shown in FIG. **4**, five terminals are provided in the housing H of the connector section C as the connector terminals T. The IGT input terminal T**1**, the IGW input terminal T**2**, and the IGW output terminal T**3** are located in this order between the supply terminal T**4** and the ground terminal T**5** located on the ends. A connecting terminal portion C**1**, which extends from the engine ECU **100**, is inserted in and fitted to the housing H of the connector section C and is connected to the connector terminals T. The connecting terminal portion C**1** includes the IGT signal line L**1** and the IGW signal line L**2** of the engine ECU **100**, which are connected to the IGT input terminal T**1** and the IGW input terminal T**2**. The IGW signal line L**2** one end of which is connected to the IGW output terminal T**3** has the other end constituting the connecting terminal portion C**1** corresponding to another ignition device **10**. The supply terminal T**4** and the ground terminal T**5** of the connector section C are connected to the supply line L**3** and a ground line L**4**.

In FIG. **2**, the main ignition circuit **3** includes the main ignition switch SW**1** and a switch drive circuit for main ignition operation (hereinafter, referred to as a main ignition drive circuit) **31**, which switches on and off the main ignition switch SW**1**. The main ignition switch SW**1** is a voltage-driven switching element such as an IGBT (that is, an insulated gate bipolar transistor). The collector terminal and the emitter terminal are electrically connected or interrupted by controlling the gate potential in accordance with a drive signal input to the gate terminal. The collector terminal of the main ignition switch SW**1** is connected to the second end of the main primary coil **21***a*, and the emitter terminal is grounded.

The main ignition drive circuit **31** generates a drive signal corresponding to the main ignition signal IGT and switches the main ignition switch SW**1** on and off. More specifically (for example, refer to IGT #1 shown in FIG. **5**), when the main ignition switch SW**1** is switched on at the rising of the main ignition signal IGT, current supply to the main primary coil **21***a* is started, so that the primary current I**1** flows. Subsequently, when the main ignition switch SW**1** is switched off at the falling of the main ignition signal IGT, the current supply to the main primary coil **21***a* is interrupted, so that a high secondary voltage V**2** is generated in the secondary coil **22** due to mutual induction. The secondary voltage V**2** is applied to the spark gap G of the ignition plug P, so that a spark discharge occurs, and the secondary current I**2** flows.

The energy supply circuit **4** includes the discharge continuing switch SW**2**, a sub-primary coil control circuit **41**, a target secondary current value detection circuit **42**, and a secondary current feedback circuit (for example, indicated as I2F/B in FIG. **2**) **43**. The sub-primary coil control circuit **41** controls current supply to the sub-primary coil **21***b* by outputting drive signals for switching on and off the discharge continuing switch SW**2**. The target secondary current value detection circuit **42** detects a set value of a target secondary current value I2tgt during the energy supply operation. The secondary current feedback circuit **43** generates a signal for feedback controlling the secondary current I**2**.

Furthermore, a switching element (hereinafter, referred to as a recirculation switch) SW**3** for opening and closing a recirculation path L**31**, which is connected to the sub-primary coil **21***b*, is provided and is switched in response to a drive signal from the sub-primary coil control circuit **41**.

The discharge continuing switch SW**2** and the recirculation switch SW**3** are, for example, MOSFETs (that is, field-effect transistors). The drain terminal of the discharge continuing switch SW**2** is connected to the second end of the sub-primary coil **21***b*, and the source terminal is grounded.

The target secondary current value detection circuit **42** detects the set value of the target secondary current value I**2**tgt instructed from the engine ECU **100** and transmits it to the secondary current feedback circuit **43**. The target secondary current value I**2**tgt is previously set in accordance with, for example, the engine operating condition in the engine ECU **100** and is indicated as, for example, pulse waveform information of the main ignition signal IGT and the energy supply signal IGW (for example, the rising phase difference).

The secondary current feedback circuit **43** compares the set value of the target secondary current value I**2**tgt with the detected value of the secondary current I**2** based on the secondary current detection resistance R**1** and outputs a feedback signal based on the comparison result to the sub-primary coil control circuit **41**.

The recirculation path L**31** is located between the second end of the sub-primary coil **21***b* (that is, the end further from the main primary coil **21***a*) and the supply line L**3**. The drain terminal of the recirculation switch SW**3** is connected to the contact point between the second end of the sub-primary coil **21***b* and the discharge continuing switch SW**2**, and the source terminal is connected to the supply line L**3** through a second diode **11**. The supply line L**3** is provided with a third diode **12** located between the contact point with the recirculation path L**31** and the DC power supply B. The forward direction of the second diode **11** is the direction toward the supply line L**3**, and the forward direction of the third diode **12** is the direction toward the primary coil **21**. Thus, when the discharge continuing switch SW**2** is off, the recirculation switch SW**3** is switched on, so that the second end of the sub-primary coil **21***b* and the supply line L**3** are connected through the recirculation path L**31**. Since the recirculation current flows during the interruption of current to the sub-primary coil **21***b*, the current through the sub-primary coil **21***b* changes gradually. This inhibits a rapid decrease in the secondary current I**2**.

Next, the ignition control performed by the engine ECU **100** and the operation of the IGW monitor **103** will be described with reference to FIG. **5**. As described above, the IGT generating section **101** of the engine ECU **100** outputs the main ignition signal IGT corresponding to each cylinder in the order of, for example, IGT #1, IGT #3, IGT #4, and IGT #2 to the corresponding IGT signal line L**1**. Upon receipt of the main ignition signal IGT, the main ignition circuit **3** is activated in the ignition device **10** of each cylinder to start the main ignition operation of the ignition coil **2**. That is, as shown with the cylinder #1 in FIG. **5**, at the rising of the main ignition signal IGT, current supply to the main primary coil **21***a* is started, and at the falling of the main ignition signal IGT, the current supply is interrupted, so that a high secondary voltage V**2** is generated in the secondary coil **22**, and thus starting the main ignition operation.

If the operating range of the engine is in an energy supply region, the IGW generating section **102** generates, after the main ignition operation is started, the energy supply signal IGW for superimposing a discharge current and outputs it to the IGW signal line L**2**. Like the main ignition signals IGT, the energy supply signals IGW are generated in the order of, for example, IGW #1, IGW #3, IGW #4, and IGW #2, and the same energy supply signals IGW are input to the ignition devices **10** of the cylinders through the common main signal line L**21**.

While the sub-primary coil control circuit **41** is receiving, for example, the main ignition signal IGT of the corresponding cylinder (that is, during the H level), the energy supply circuit **4** extracts a signal input from the main signal line L**21** as the energy supply signal IGW of that cylinder and performs the energy supply operation at a predetermined point in time. At this time, for example, the target secondary current value detection circuit **42** detects the target secondary current value I**2**tgt, which is indicated by the rise time difference Ta between the main ignition signal IGT and the energy supply signal IGW, and outputs it to the secondary current feedback circuit **43**. The secondary current feedback circuit **43** outputs, to the sub-primary coil control circuit **41**, the result obtained by comparing the detected value of the secondary current I**2** based on the secondary current detection resistance R**1** with the threshold value based on the set value of the target secondary current value I**2**tgt.

With this configuration, the sub-primary coil control circuit **41** causes current to be supplied to the sub-primary coil **21***b* to seek the set value of the target secondary current value I**2**tgt, thus performing the energy supply operation. In an energy supply time period during which the energy supply operation is performed, the secondary voltage V**2** of the secondary coil **22** is kept at a discharge maintaining voltage lower than that during the main ignition operation. The energy supply time period is instructed by, for example, the falling signal of the main ignition signal IGT and the energy supply signal IGW, and when the energy supply time period ends by the falling of the energy supply signal IGW, current supply to the sub-primary coil **21***b* is stopped, so that the secondary voltage V**2** of the secondary coil **22** is decreased.

The IGW monitor **103** includes the first monitor terminal M**1**, which monitors the energy supply signal IGW output from the IGW generating section **102** as it is, and the second monitor terminal M**2**, which monitors the signal that has passed through the ignition devices **10**, and determines the presence/absence of an abnormality by comparing the monitored values. More specifically, as shown in Table 1 below, an abnormality in the signal path of the energy supply signal IGW can be determined by comparing the instruction from the engine ECU **100** with the input value of the first monitor terminal M**1** (first monitor value) and further comparing the first monitor value with the input value of the second monitor terminal M**2** (second monitor value).

TABLE 1

Signal output instruction	First monitor value	Second monitor value	Determination result	IGW circuit abnormality	IGW signal disconnection
Issued	Same as instruction signal	Same as instruction signal	Cylinder #N is normal/ No disconnection	No abnormality	No disconnection

TABLE 1-continued

Signal output instruction	First monitor value	Second monitor value	Determination result	IGW circuit abnormality	IGW signal disconnection
Issued	Same as instruction signal	Held to OFF (L)	Cylinder #N is normal/ Disconnection after cylinder #N	No abnormality	Disconnection has occurred (other cylinders)
Issued	Differs from instruction signal	Same as first monitor value	Abnormality in cylinder #N/ No disconnection	Abnormality exists	No disconnection
Issued	Differs from instruction signal	Held to OFF (L)	Abnormality in cylinder #N/ Disconnection after cylinder #N	Abnormality exists	Disconnection has occurred (other cylinders)

An IGW path abnormality determination process for the ignition device **10** of each cylinder performed by the IGW monitor **103** will be described with reference to Table 1 in accordance with the flowchart shown in FIG. **6**.

In this routine, the IGW path abnormality determination process is performed sequentially for all the cylinders with the numerals of the cylinders set to #N (#1 to #4). In this case, as shown in Table 1, a disconnection in the main signal line L**21** of the energy supply signal IGW (IGW signal disconnection) and an abnormality in the energy supply circuit **4** monitored by the circuit abnormality determination section **53** (IGW circuit abnormality) can be separately detected for each cylinder.

The routine may be performed by transmitting a signal for checking, for example, before and after starting the engine or when the engine is stopped besides during the operation that involves the energy supply operation. In this case, the IGW path abnormality determination process does not necessarily have to be performed for all the cylinders.

When the IGW path abnormality determination process is started in FIG. **6**, first, at step S**1**, it is determined whether the energy supply signal IGW is output to the cylinder #N from the IGW generating section **102** in response to the energy supply instruction from the engine ECU **100** (that is, is IGW signal output?). If the operating condition of the engine is in the previously set energy supply operation region, the engine ECU **100** outputs, subsequent to the main ignition signal IGT, the energy supply signal IGW at a predetermined point in time, so that the signal voltage level is switched from the L level to the H level (for example, from 0V to 12V).

If the decision outcome of step S**1** is negative, this iteration of the routine is terminated.

If the decision outcome of step S**1** is positive (that is, if the signal output instruction in Table 1 is "Issued"), the process proceeds to step S**2**, and the first monitor value is acquired from the first monitor terminal M**1**, and the second monitor value is acquired from the second monitor terminal M**2**. Subsequently, the process proceeds to step S**3**, and it is determined whether the first monitor value is equal to the output value of the energy supply signal IGW (that is, first monitor value=IGW output value?). If the decision outcome of step S**3** is positive, the process proceeds to step S**4**, and if the decision outcome of step S**3** is negative, the process proceeds to step S**5**.

At step S**4**, it is determined that the first monitor value is equal to the output value of the energy supply signal IGW (that is, the first monitor value in Table 1 is "Same as instruction signal"), and thus the energy supply circuit **4** of the cylinder #N is normal (that is, the circuit abnormality in Table 1 is "No abnormality"). In this case, the count of the number of abnormalities is cleared (that is, number of abnormalities=0), and then the process proceeds to step S**6**.

At step S**5**, it is determined that the first monitor value differs from the output value of the energy supply signal IGW (that is, the first monitor value in Table 1 is "Differs from instruction signal") and thus there is an abnormality in the energy supply circuit **4** of the cylinder #N (that is, the circuit abnormality in Table 1 is "Abnormality exists"). In this case, the count of the number of abnormalities is incremented (number of abnormalities=number of abnormalities+1), and the process proceeds to step S**6**.

In FIG. **1**, when the cylinder #N is being checked for example, if the signal level holding section **55** of the corresponding ignition device **10** is operated, the main line L**211** is held to the L level. Thus, the main signal line L**21**, which is connected to the main line L**211**, also has the same potential. Consequently, the first monitor value detected on one end of the main signal line L**21** differs from the instruction from the engine ECU **100**. Monitoring the difference allows an abnormality to be detected.

At step S**6**, it is determined whether the signal level of the second monitor value is in the off state (that is, is the second monitor value OFF?). If the decision outcome of step S**6** is negative, the process proceeds to step S**7**, and it is further determined whether the second monitor value is equal to the first monitor value (that is, first monitor value=second monitor value?).

If the decision outcome of step S**7** is positive, at step S**8**, it is determined that there is no disconnection of the signal path of the energy supply signal IGW (that is, the disconnection in Table 1 is "No disconnection"). In this case, the count for the number of disconnections is cleared (that is, number of disconnections=0), and then this iteration of the routine is terminated.

If the decision outcome of step S**7** is negative, this iteration of the routine is terminated as it is.

In FIG. **1**, if a disconnection occurs in a given position in the main signal line L**21**, the energy supply signal IGW is not transmitted to the cylinders after the disconnection location. In other words, if the second monitor value, which is at the distal end of the main signal line L**21**, is held to the L level, it means there is a disconnection. Thus, the disconnection can be detected by monitoring the second monitor value.

In FIG. **1**, if there is no disconnection anywhere in the main signal line L**21**, the signal level on both ends of the main signal line L**21** will be the same potential regardless of the presence/absence of the circuit abnormality in the energy supply circuit **4** of the ignition devices **10** (that is, the second monitor value in Table 1 is "Same as instruction signal" or "Same as first monitor value").

If the decision outcome of step S**6** is positive (that is, the second monitor value in Table 1 is "Hold to OFF (L)"), at step S**9**, it is determined that there is a disconnection in the signal path of the energy supply signal IGW (that is, the disconnection in Table 1 is "Disconnection has occurred"). In this case, the count for the number of disconnections is incremented (that is, number of disconnections=number of disconnections+1). Subsequently, this iteration of the routine is terminated.

In this manner, events such as a circuit abnormality and a disconnection in the signal path of the energy supply signal IGW are detected using the first monitor value and the second monitor value.

As shown in Table 1, the state in which it is determined that a circuit abnormality exists at step S**5** further includes a case in which a disconnection has occurred and a case in which a disconnection does not exist. If the first monitor value and the second monitor value are the same, it is determined that there is a circuit abnormality in the cylinder #N, and if the second monitor value differs from the first monitor value and is held to OFF, it is determined that a disconnection has occurred.

The first monitor value and the second monitor value may be acquired by sensing the signal level at certain intervals while the energy supply signal IGW is output and may be compared with the IGW output instruction value, or may be compared with an IGW output signal using a comparison circuit such as an exclusive OR circuit. The comparison may be performed during the entire time period in which the energy supply signal IGW is output, or only during the time period from the falling of the main ignition signal IGT to the falling of the energy supply signal IGW, or just at a predetermined point in time including the point in time in which the circuit abnormality is detected during the IGW output time period.

The operations of the abnormality counter and the disconnection counter are not limited to the above-described method of the present embodiment. For example, in the above-described method, instead of clearing the abnormality or disconnection counter (that is, number of abnormalities or number of disconnections=0), the abnormality or disconnection counter may be decremented (that is, number of abnormalities or number of disconnections=number of abnormalities or number of disconnections−1), and the weights of the abnormality determination and the normal determination may be changed. Furthermore, the determination may be made without using the counters.

In this case, the disconnection location is temporarily determined using the relationship shown in Table 1 by performing the routine on all the cylinders. For example, if the order of ignition of the four cylinders is #1→#3→#4→#2, and the order of wiring of the energy supply signal IGW is #1→#2→#3→#4→ECU, the disconnection location is determined as follows.

If it is determined that the circuit is normal in the cylinder #1 and that there is a disconnection, the disconnection has occurred anywhere from the cylinder #1 to #4 and ECU.

If it is determined that the circuit is normal in the cylinder #3 and that there is a disconnection, the disconnection has occurred anywhere from the cylinder #3 to #4 and ECU.

If it is determined that the circuit is normal in the cylinder #4 and that there is a disconnection, the disconnection has occurred anywhere from the cylinder #4 to ECU.

If it is determined that the circuit is normal in the cylinder #2 and that there is a disconnection, the disconnection has occurred anywhere in the cylinder #2 to #4 and ECU.

Similarly, if there is a circuit abnormality in each cylinder, the disconnection location is more accurately determined using the relationship shown in Table 1.

In this case, in FIG. **1**, if there is no disconnection in the main signal line L**21**, the signal on one end of the main signal line L**21** and the signal on the other end are always the same (that is, the second monitor value in Table 1 is "Same as first monitor value"). Thus, the signal level when there is an abnormality is set to the L level not for the entire time period of the IGW signal. This allows the circuit abnormality to be distinguished from the case when there is a disconnection. Consequently, an abnormality in the signal path is determined in more detail.

For example, in the case in which the ignition order of the four cylinders is #1→#3→#4→#2, and the order of wiring of the energy supply signal IGW is #1→#2→#3→#4→ECU, the disconnection location is determined as follows.

If it is determined that there is a circuit abnormality in the cylinder #1 and that there is a disconnection, the disconnection has occurred anywhere from the cylinder #1 to #4 and the ECU.

If it is determined that there is a circuit abnormality in the cylinder #3 and that there is a disconnection, the disconnection has occurred anywhere from the cylinder #3 to #4 and ECU.

If it is determined that there is a circuit abnormality in the cylinder #4 and that there is a disconnection, the disconnection has occurred anywhere from the cylinder #4 to ECU.

If it is determined that there is a circuit abnormality in the cylinder #2 and that there is a disconnection, the disconnection has occurred anywhere from the cylinder #2 to #4 and ECU.

The IGW path abnormality determination process for the ignition device **10** of each cylinder performed by the IGW monitor **103** will be described with reference to Table 1 in accordance with the flowchart of FIG. **6**.

In this routine, the IGW path abnormality determination process is performed sequentially for all the cylinders with the numerals of the cylinders set to #N (#1 to #4). In this case, as shown in Table 1, a disconnection in the main signal line L**21** of the energy supply signal IGW (IGW signal disconnection) and an abnormality in the energy supply circuit **4** monitored by the circuit abnormality determination section **53** (IGW circuit abnormality) can be separately detected for each cylinder.

The engine ECU **100** determines the need for the operation of, for example, an external notification system in accordance with the number of abnormalities and the number of disconnections counted by the IGW path abnormality determination process in FIG. **6** prior to, for example, the generation of the energy supply signal IGW in the IGW generating section **102**. An exemplary process for generating the energy supply signal IGW performed for each cylinder (hereinafter, referred to as the IGW signal generation process) in this case will be described using the flowchart shown in FIG. **7**.

In FIG. **7**, when the IGW signal generation process is started for the cylinder #N, first, at step S**11**, it is determined whether the number of abnormalities of the cylinder #N detected by the IGW monitor **103** is greater than or equal to a predetermined number of times N1 (that is, IGW circuit of #N, number of abnormalities≥N1?). If the decision outcome of step S**11** is negative, the process proceeds to step S**12**, and it is determined whether the number of disconnections detected by the IGW monitor **103** is greater than or equal to a predetermined number of times N2 (that is, IGW signal of #N, number of disconnections≥N2?).

Steps S**11** and S**12** are for avoiding erroneous detection of a circuit abnormality or a disconnection, and the predetermined number of times N1 and N2 can be set to a certain number of times (for example, the predetermined number of times N1=10, and the predetermined number of times N2=10).

If the decision outcome of step S**11** is positive, the process proceeds to step S**13**. At step S**13**, as the measures taken when an abnormality occurs in the energy supply circuit **4** of the ignition device **10**, for example, an occupant may be notified of the occurrence of the abnormality by turning on a warning light using the notification system of the vehicle. Alternatively, the air-fuel ratio (A/F) set in the fuel injection system of the engine may be changed to be richer to avoid the deterioration of the ignitability when the energy supply operation is not performed. Subsequently, this iteration of the routine is terminated.

If the decision outcome of step S**12** is positive, the process proceeds to step S**14**. At step S**14**, for example, an occupant may be notified using the notification system of the vehicle, or the air-fuel ratio may be changed to ensure the ignitability like in step S**13** as the measures taken when a disconnection occurs. The routine is then temporarily suspended.

If the decision outcome of step S**12** is negative, the process proceeds to step S**15**, and the current engine operating condition is read. Subsequently, at step S**16**, it is determined whether the engine is in the previously set energy supply operation region in accordance with the engine operating conditions such as the engine rotational speed and the load. If the decision outcome of step S**16** is negative, this iteration of the routine is terminated.

If the decision outcome of step S**16** is positive, the process proceeds to step S**17**, and the energy supply time period and the target secondary current value I**2**tgt when the energy supply operation is performed are set for the ignition device **10** of the cylinder #N. The engine ECU **100** can have the map of the energy supply time period and the target secondary current value I**2**tgt corresponding to the engine operating region previously stored therein.

Subsequently, the process proceeds to step S**17**, and the energy supply signal IGW is output in accordance with the energy supply time period and the target secondary current value I**2**tgt set at step S**16**. As described above, the target secondary current value I**2**tgt is indicated by the rising phase difference (for example, the rise time difference Ta) between the main ignition signal IGT and the energy supply signal IGW and indicates the end of the energy supply time period by the falling of the energy supply signal IGW. Thus, a pulsed energy supply signal IGW is generated at an appropriate point in time in accordance with the set values of the energy supply time period and the target secondary current value I**2**tgt and is transmitted to the main signal line L**21**.

The routine is then temporarily suspended.

According to the configuration of the present embodiment, the IGW signal line L**2** located between the engine ECU **100** and the ignition devices **10** is constituted by the common main signal line L**21** and the bifurcated portions **5***a* to **5***d*, which sequentially bifurcate inside the ignition devices **10**. Thus, the branched portions are not formed in the middle of the wiring connecting between the devices, and the reliability of the wiring is improved. Since the branched portions do not concentrate, an increase in the size of the branched portions or an increase in the rigidity does not occur, which increases the degree of freedom in mounting the wiring.

Since the main signal line L**21** sequentially passes through the ignition devices **10** and returns to the engine ECU **100** from the main line L**211** of the last bifurcated portion **5***d*, a disconnection in the main signal line L**21** is detected by monitoring the signal of the signal path by the IGW monitor **103**. Furthermore, inside each ignition device **10**, the branched line L**22** of the associated one of the bifurcated portions **5***a* to **5***d* is connected to the energy supply circuit **4**, and the main line L**211** is connected to the signal level holding section **55**, which is operated when an abnormality occurs in the energy supply circuit **4**. Thus, the IGW monitor **103** detects an abnormality in the energy supply circuit **4**.

The IGW monitor **103** can be operated not only when the energy supply operation is performed but also in a region other than the energy supply region. For example, the main ignition signal IGT and the energy supply signal IGW may be sequentially output to the ignition devices **10** of the cylinders before starting the engine after the power supply is switched on or after the engine is stopped to detect an abnormality or a disconnection in the energy supply circuit **4**.

This increases the detection frequency of the IGW monitor **103**, enables detecting a circuit abnormality and a disconnection before the energy supply operation, and improves the reliability of the ignition control system **1**. The main ignition signal IGT and the energy supply signal IGW in this case are preferably output at a minimum time period necessary for checking with an energy that does not influence the engine combustion.

Second Embodiment

An ignition control system for an internal combustion engine according to a second embodiment will be described with reference to FIGS. **8** and **9**.

In the first embodiment, the bifurcated portions **5***a* to **5***d* of the IGW signal line L**2** are located inside the ignition devices **10**. In the present embodiment, however, the bifurcated portions **5***a* to **5***d* corresponding to the ignition devices **10** are located outside of the connector sections C of the ignition devices **10**, and the IGW output terminals T**3** are omitted as shown in FIG. **8**. Other basic structures of the ignition devices **10** and the engine ECU **100** are the same as those of the first embodiment, and the differences from the first embodiment will mainly be described below.

The reference numerals used in and after the second embodiment that are the same as the reference numerals in the previously described embodiment refer to the same components as those in the previously described embodiment unless otherwise specified.

In the present embodiment, the structure of the connector section C of each ignition device **10** is the same as that in the first embodiment, and the four IGT signal lines L**1** (L**1** #1 to L**1** #4) provided for the cylinders are each connected to the IGT input terminal T**1** of the associated connector section C. The IGW signal line L**2** includes the main signal line L**21** common to the four ignition devices **10** and the four bifurcated portions **5***a* to **5***d* corresponding to the four ignition devices **10**. The common main signal line L**21** includes one end connected to the IGW generating section **102** and the other end that bifurcates one after the other from the main signal line L**21** to form the bifurcated portions **5***a* to **5***d*.

First, the bifurcated portion **5***a* corresponding to one of the four ignition devices **10** (for example, the ignition device #1 corresponding to the cylinder #1) branches from the main signal line L**21**. The branch point **51** of the bifurcated portion **5***a* is located close to the outside of the connector section C, and the branched line L**22**, which branches from the branch point **51** is connected to the IGW input terminal T**2** and is connected to the energy supply circuit **4** inside the ignition device **10**. The other line connected to the branch point **51** of the bifurcated portion **5***a* is the main line L**211**, which constitute part of the main signal line L**21** and forms a pair with the branched line L**22**. The main line L**211** is connected to another ignition device **10** (for example, the ignition device #2 corresponding to the cylinder #2) as it is. In the ignition device **10** of the cylinder #1, the basic structure of the signal level holding section **55** is the same as that of the first embodiment, and the switching element **54** is connected to the contact point **52** provided on the branched line L**22**, which is connected to the IGW input terminal T**2**.

The bifurcated portion **5***b* subsequently branches from the main signal line L**21**, which serves as the main line L**211** of the bifurcated portion **5***a*, and the branched line L**22** of the bifurcated portion **5***b* is connected to the energy supply circuit **4** inside the ignition device **10** of the cylinder #2. The bifurcated portion **5***c* and the bifurcated portion **5***d* further sequentially branch from the main line L**211** of the bifurcated portion **5***b*. The branched line L**22** of the bifurcated portion **5***c* is connected to the energy supply circuit **4** in the ignition device **10** of the cylinder #3, and the branched line L**22** of the bifurcated portion **5***d* is connected to the energy supply circuit **4** in the ignition device **10** of the cylinder #4. The bifurcated portion **5***d* that branches last includes the main line L**211** connected to the branch point **51**. The main line L**211** serves as the distal end of the main signal line L**21** as it is and is connected to the IGW monitor **103** of the engine ECU **100**.

With the bifurcated portions **5***a* to **5***d* configured as described above also, the engine ECU **100** and the four ignition devices **10** are connected by one continuous main signal line L**21**. One end of the main signal line L**21** is connected to the first monitor terminal M**1** of the IGW monitor **103** through the signal line L**20**, and the distal end of the main signal line L**21** is connected to the second monitor terminal M**2**. Thus, a circuit abnormality and a disconnection can be detected in the same manner.

The branching position of the bifurcated portion **5***a* is preferably at, for example, a position closer to the ignition device **10** than half the entire length of the main signal line L**21** between the engine ECU **100** and the connector section C of the ignition device **10** of the cylinder #1. Furthermore, similarly, the branching position of each of the bifurcated portions **5***b* to **5***d* located between the ignition devices **10** is preferably at a position closer to the output end than half the entire length of the main signal line L**21** from which each of the bifurcated portions **5***b* to **5***d* branches.

This further reduces the length of the main line L**211**, which extends from the branch point **51** to the next ignition device **10**, so that the bifurcated portions **5***a* to **5***d* are reduced in size, and the degree of freedom in mounting the signal line is improved. Additionally, since the length of the path is reduced, the influence of the electrical noise radiation from the inside of the ignition devices **10** and the external noise is reduced. Each of the bifurcated portions **5***a* to **5***d* is preferably located at the connecting terminal portion C**1**, which is connected to the connector section C of each ignition device **10** (for example, refer to FIG. **4**), or on the connection end of the main signal line L**21** close to the connecting terminal portion C**1**.

FIG. **9** is an exemplary configuration of a case in which each of the bifurcated portions **5***a* to **5***d* is provided at the connecting terminal portion C**1** and shows the main part of a connecting terminal C**2** of the IGW signal line L**2** in the connecting terminal portion C**1**. For example, as shown on the left side in FIG. **9**, the connecting terminal C**2** of the IGW signal line L**2** includes a holder C**21** and a terminal portion C**22**. The holder C**21** holds the main signal line L**21**, which extends from the engine ECU **100**, together with the signal line that serves as the main line L**211** of the bifurcated portion **5***a*. The terminal portion C**22** is connected to the IGW input terminal T**2** of the connector section C. The holder C**21** and the terminal portion C**22** are integrated. Two signal lines including the main signal line L**21** and the main line L**211** of the bifurcated portion **5***a* are arranged side by side in the tubular holder C**21** with the insulation film removed and are crimped inside a crimp portion C**23**.

The bifurcated portion **5***b*, which branches from the main line L**211** of the bifurcated portion **5***a*, has the same structure. The main line L**211**, which extends from the rear end of the holder C**21** (that is, the end further from the terminal portion C**22**), is connected to the rear end of the connecting terminal C**2** at which the bifurcated portion **5***b* is formed.

As shown on the right side in FIG. **9**, the connecting terminal C**2** does not necessarily have to be provided with the holder C**21**. Two signal lines including the main signal line L**21** and the main line L**211** of the bifurcated portion **5***a* may be integrally crimped at a crimp portion C**24** with the insulation film being removed from the crimped portion.

With the configuration according to the present embodiment also, since the IGW signal line L**2**, which is located between the engine ECU **100** and the ignition devices **10**, is constituted by the common main signal line L**21** and the bifurcated portions **5***a* to **5***d*, which are sequentially bifurcated outside the ignition devices **10**, the compact, highly reliable ignition control system that achieves the same advantages as the first embodiment is provided.

In each of the above embodiments, the main signal line L**21** drawn out from the last bifurcated portion **5***d* among the bifurcated portions **5***a* to **5***d* of the IGW signal line L**2** returns to the IGW monitor **103** of the engine ECU **100**. However, a different structure may be employed. For example, an abnormality diagnosis device for a vehicle inspection may be provided outside instead of the IGW monitor **103**. The main signal line L**21** that is drawn out from the last bifurcated portion **5***d* may be connected to the abnormality diagnosis device to perform an abnormality diagnosis.

The IGW monitor **103** is provided with the first monitor terminal M**1** and the second monitor terminal M**2** and receives the signals from both ends of the main signal line L**21** for comparing the signals. However, the signals may be separately monitored, or only one of the signals need to be monitored. More preferably, only the second monitor terminal M**2** needs to be monitored.

Third Embodiment

An ignition control system for an internal combustion engine according to a third embodiment will be described with reference to FIG. **10**.

In each of the above embodiments, the last bifurcated portion **5***d* among the bifurcated portions **5***a* to **5***d* of the IGW signal line L**2** returns to the IGW monitor **103**.

However, the ignition control system **1** does not necessarily have to include the second monitor terminal M**2** of the IGW monitor **103**.

In this case, the wiring to the IGW output terminal T**3** of the last bifurcated portion **5***d* may be omitted, and the IGW output terminal T**3** may be covered with a dummy plug, for example. This simplifies the circuit and reduces the costs.

Alternatively, the IGW output terminal T**3** of the connector section C to which the last bifurcated portion **5***d* is connected may be the second IGW input terminal T**2**, and the last bifurcated portion **5***d* may be connected to the IGW generating section **102** through a sub-signal line L**23**. In this case, for example, as shown on the upper side in FIG. **10**, the sub-signal line L**23** may branch from the main signal line L**21** at an output terminal **102***a* of the IGW generating section **102**. The main signal line L**21** may be connected to the ignition device **10** of the cylinder #1, and the sub-signal line L**23** may be connected to the ignition device **10** of the cylinder #4. Alternatively, as shown on the lower side in FIG. **10**, one end of the main signal line L**21** may be connected to the output terminal **102***a* of the IGW generating section **102**, and one end of the sub-signal line L**23** may be connected to an output terminal **102***b* of the IGW generating section **102**. The other end of the main signal line L**21** may be connected to the ignition device **10** of the cylinder #1, and the other end of the sub-signal line L**23** may be connected to the ignition device **10** of the cylinder #4. The structure in which the bifurcated portions **5***a* to **5***d* of the IGW signal line L**2** are provided corresponding to the ignition devices **10** is the same as each of the above-described embodiments.

With the configuration in which the energy supply signal IGW is input from both ends of the IGW signal line L**2** as described above, even if, for example, a disconnection occurs anywhere in the main signal line L**21** including the bifurcated portions **5***a* to **5***d*, the energy supply operation can be performed using the energy supply signal IGW input from either the main signal line L**21** connected to the bifurcated portion **5***a* or the sub-signal line L**23** connected to the bifurcated portion **5***d*.

With the configuration according to the present embodiment also, since the IGW signal line L**2**, which is located between the engine ECU **100** and the ignition devices **10**, is constituted by the common main signal line L**21** and the bifurcated portions **5***a* to **5***d*, which are sequentially bifurcated inside the ignition devices **10**, the compact, highly reliable ignition control system that achieves the same advantages as the first embodiment is provided.

The present disclosure is not limited to the above embodiments, and various modifications are possible without departing from the scope of the disclosure. For example, the main ignition signal IGT and the energy supply signal IGW are described in accordance with the case of the positive logic signal in which the signal voltage at the H level represents logic 1. However, the negative logic signal in which the potential is reversed may be employed.

The configuration of the ignition coil **2** and the energy supply circuit **4** may be modified as required. For example, in the configuration of the first embodiment, two sets of ignition coils **2** each including the primary coil **21** and the secondary coil **22** may be provided as disclosed in International Publication 2017/010310. In this case, the two sets of ignition coils **2** are connected in series as the main ignition coil and the sub-ignition coil. While the main ignition operation of the main ignition coil is performed by the main ignition circuit **3**, the energy supply operation of the sub-ignition coil is performed by the energy supply circuit **4** to superimpose the generated energy on the main ignition coil with the same polarity.

Alternatively, one set of ignition coil **2** including the primary coil and the secondary coil may be provided. While the main ignition operation is performed by the main ignition circuit **3**, the energy supply operation is performed using the energy supply circuit **4** including a boost circuit and a capacitor, so that the energy stored in the capacitor by the boost circuit is input from the low potential side of the primary coil **21**, and thus superimposing current having the same polarity.

As described above, the energy supply circuit **4** for performing the energy supply operation to the ignition coil **2** is not limited to the configuration shown in the first embodiment, but may have any configuration as long as the energy supply operation is performed after the main ignition operation, so that the secondary current I**2** having the same polarity is superimposed.

The internal combustion engine does not necessarily have to be a gasoline engine for automobiles, but may be various spark ignition internal combustion engines. The configuration of the ignition coil **2** and the ignition devices **10** may be changed as required in accordance with the internal combustion engine on which the ignition coils **2** and the ignition devices **10** are mounted.

In the above-described embodiments, the IGW signal line is branched and connected to the ignition devices **10** with the bifurcated portions provided for the ignition devices **10** of all the cylinders. However, the IGW signal line only needs to be bifurcated to connect to two or more ignition devices **10** and does not necessarily have to connect to all the cylinders.

What is claimed is:

1. An ignition control system for an internal combustion engine comprising:

a plurality of ignition devices corresponding to a plurality of cylinders of the internal combustion engine, and

a controller, which outputs signals for controlling the ignition devices, wherein

each ignition device includes:

an ignition coil, which generates discharge energy in a secondary coil connected to an ignition plug by an increase and decrease in a primary current that flows through a primary coil, a main ignition circuit, which controls current supply to the primary coil to perform a main ignition operation that causes a spark discharge at the ignition plug, and an energy supply circuit, which performs an energy supply operation that superimposes current on a secondary current that flows through the secondary coil by the main ignition operation,

the controller includes:

an IGT generating section, which generates a main ignition signal for controlling the main ignition operation, and an IGW generating section, which generates an energy supply signal for controlling the energy supply operation, wherein

the controller is connected to the ignition devices through an IGT signal line for transmitting the main ignition signal and an IGW signal line for transmitting the energy supply signal,

the IGW signal line includes a common main signal line having one end connected to the controller and a plurality of bifurcated portions, which sequentially bifurcate from the main signal line, wherein the bifurcated portions each correspond to one of the ignition devices and include a branched line, which is connected to the energy supply circuit inside the corresponding ignition device,

the bifurcated portions each include a main line, which forms a pair with the branched line, and the main lines are connected in series with each other and form a part of the main signal line,

the controller includes an IGW monitor, which is connected to a signal path of the IGW signal line and monitors the energy supply signal, and

the IGW monitor receives a signal from the main line of the bifurcated portion that branches last from the main signal line, which serves as a distal end of the signal path of the IGW signal line, and the IGW monitor compares the signal input from the distal end with the energy supply signal output to one end of the main signal line from the IGW generating section to determine whether there is an abnormality.

2. The ignition control system for the internal combustion engine according to claim **1**, wherein

the bifurcated portions are each located inside the corresponding ignition device or on an end connected to the corresponding ignition device.

3. The ignition control system for the internal combustion engine according to claim **2**, wherein

each ignition device includes a connector section, which includes an IGT input terminal, to which the IGT signal line is connected, and an IGW input terminal and an IGW output terminal, to which the main signal line is connected, and

the bifurcated portions are each located between the IGW input terminal and the energy supply circuit in the associated ignition device, and the main line is connected to the IGW output terminal.

4. The ignition control system for the internal combustion engine according to claim **2**, wherein

each ignition device includes a connector section, which includes an IGT input terminal, to which the IGT signal line is connected, and an IGW input terminal and an IGW output terminal, to which the main signal line is connected, and

the bifurcated portions are each located at the connecting terminal portion of the main signal line, which is connected to the connector section.

5. The ignition control system for the internal combustion engine according to claim **3**, wherein

each ignition device includes a signal level holding section, which holds a level of a signal of the main signal line to an off state when an abnormality is detected in the energy supply circuit.

6. The ignition control system for the internal combustion engine according to claim **2**, wherein

the IGW signal line includes a sub-signal line, which connects the main line of the bifurcated portion that branches last from the main signal line to the IGW generating section and transmits the energy supply signal from the IGW generating section.

7. The ignition control system for the internal combustion engine according to claim **1**, wherein

the primary coil of the ignition coil includes a main primary coil and a sub-primary coil, and the energy supply circuit controls current supply to the sub-primary coil to control the energy supply operation.

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